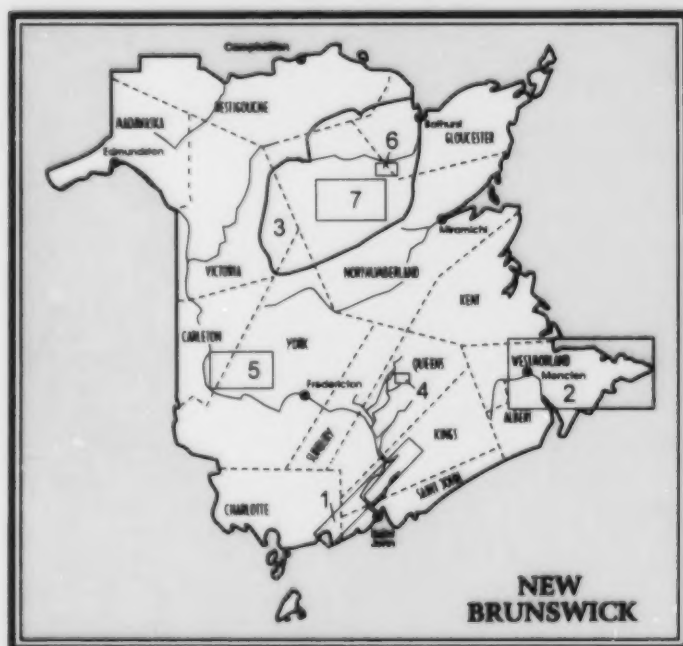


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Cover Illustration: Index to papers in this volume:

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2.  $^{40}\text{Ar}/^{39}\text{Ar}$  dating of detrital muscovite from post-Viséan sandstones, southeastern New Brunswick (Johnson)
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7. Lithogeochemistry, petrography, geochronology of Ordovician rocks, Big Bald Mountain, NTS 21 O/1 (Wilson, Fyffe, McNicoll, Wodicka)

 Bathurst Mining Camp

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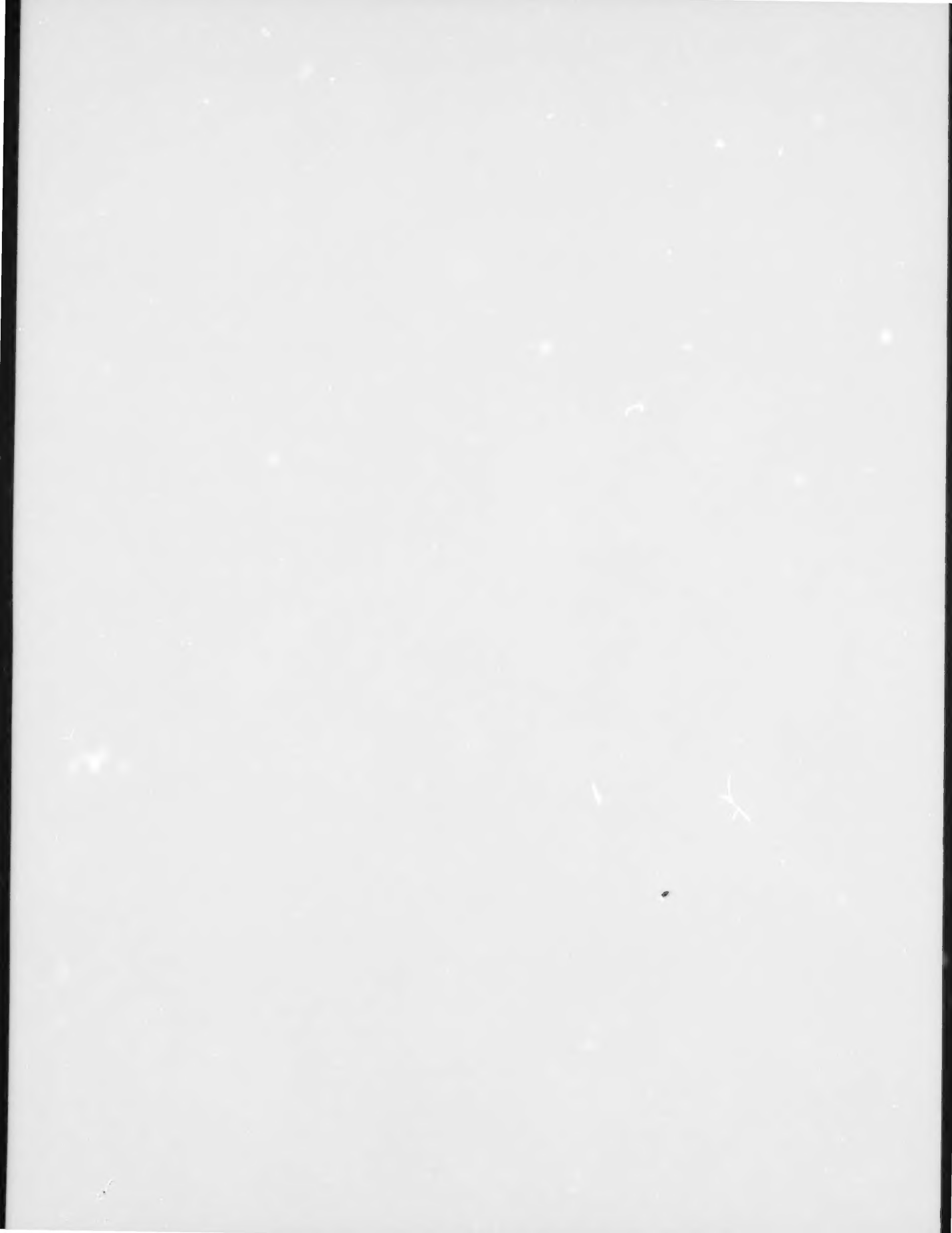
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# GEOLOGY OF THE SILURIAN KINGSTON TERRANE, SOUTHERN NEW BRUNSWICK ††

Sandra M. Barr<sup>1</sup>, Chris E. White<sup>2</sup>, and Malcolm J. McLeod<sup>3</sup>

<sup>1</sup>Department of Geology, Acadia University, Wolfville, Nova Scotia, CANADA B0P 1X0

(e-mail: sandra.barr@acadiau.ca)

<sup>2</sup>Nova Scotia Department of Natural Resources, P.O. Box 698, Halifax, Nova Scotia, CANADA B3J 2T9

<sup>3</sup>New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch,  
P.O. Box 5040, Sussex, New Brunswick, CANADA E4E 5L2

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The Kingston terrane of southern New Brunswick consists mainly of Silurian volcanic and granitoid rocks intruded by abundant mafic sheets. The volcanic rocks, together with minor interbedded epiclastic sedimentary rocks, are assigned to the Bayswater Group, with the type area on the Kingston Peninsula where a Silurian age (ca. 435 Ma) was previously determined by U-Pb dating. The Bayswater Group is divided, on a preliminary basis, into six units composed dominantly of rhyolitic to dacitic lithic and lithic-crystal, crystal lapilli tuff, and less abundant flows, as well as basaltic and andesitic tuff and flows, and minor interbedded epiclastic wacke and siltstone. The sequence youngs to the northwest. Granitoid plutons form about half of the terrane, and are characterized by fine grain size and abundant granophyric and porphyritic textures, indicative of high-level emplacement. The felsic volcanic and granitoid rocks are chemically similar, with compositions consistent with calc-alkalic affinity and emplacement in a continental margin volcanic arc. Tholeiitic mafic sheets intruded both the plutons and the Bayswater Group, and chemical compositions appear to reflect extension in a volcanic arc setting.

The Bayswater Group, granitoid plutons, and mafic sheets contain mineral assemblages consistent with upper greenschist facies metamorphism. Relict primary layering, metamorphic foliation, and mafic sheet orientation are generally parallel and near-vertical, and trend northeast in the southwestern part of the terrane but generally north-northeast in the northeastern part of the terrane. The rocks commonly display a steep intersection lineation throughout the terrane.

Le terrane de Kingston dans le Sud du Nouveau-Brunswick est principalement constitué de roches volcaniques et granitoïdes du Silurien pénétrées par des nappes mafiques abondantes. On attribue les roches volcaniques et la petite quantité présente de roches sédimentaires épicastiques interstratifiées au groupe de Bayswater, dont la région type se trouve sur la péninsule de Kingston, où l'on a déjà relevé des roches de l'époque du Silurien (env. 435 Ma) par datation au U-Pb. Le groupe de Bayswater a préliminairement été divisé en six unités, principalement composées de conglomérat volcanique à lapilli cristallin, de tuf cristal-lithique et rhyolithique à litho-dacitique, d'écoulements moins abondants, ainsi que de tuf et d'écoulements basaltiques et andésitiques, et d'une faible quantité de siltstone et de wacke épicastique interstratifiés. La séquence rajeunit vers le nord-ouest. Des plutons granitoïdes forment à peu près la moitié du terrane; ils se caractérisent

†† Funding provided by the New Brunswick Geological Surveys Branch ordinary budget and a research grant to S.M. Barr from the Natural Sciences and Engineering Research Council of Canada.

par leurs grains fins et leurs structures granophyriques et porphyriques abondantes, qui témoignent de leur mise en place à un niveau élevé. Les roches volcanofelsiques et granitoïdes sont semblables du point de vue chimique; leurs compositions correspondent à une affinité calco-alcaline et à leur emplacement dans un arc insulaire de marge continentale. Des nappes mafico-tholéiitiques font intrusion dans les plutons et dans le groupe de Bayswater; leurs compositions chimiques semblent correspondre à un prolongement dans un cadre d'arc insulaire.

Le groupe de Bayswater, les plutons granitoïdes et les nappes mafiques renferment des assemblages minéraux compatibles avec un métamorphisme supérieur du faciès des schistes verts. La stratification primaire résiduelle, le feuilletage métamorphique et l'orientation des nappes mafiques sont généralement parallèles et quasi verticales; ils sont orientés vers le nord-est dans la partie sud-ouest du terrane, mais généralement vers le nord-nord-est dans la partie nord-est du terrane. Les roches affichent communément une forte linéation d'intersection partout dans le terrane.

## INTRODUCTION

The Kingston terrane is a narrow northeast-trending belt of mainly Silurian rocks in southern New Brunswick (Figure 1). It is separated by major faults from predominantly Precambrian rocks of the Brookville terrane to the southeast and the New River terrane to the northwest (Figure 1). Although previously reported to consist mainly of a mafic-felsic dyke swarm (McCutcheon and Ruitenberg 1987; Currie 1984, 1997; Eby and Currie 1993; McLeod *et al.* 1994), mapping in the Kingston Peninsula has demonstrated that volcanic and comagmatic granitoid plutons form most of the belt, although mafic dykes are abundant (Grant 1971; O'Brien 1976; Barr *et al.* 1997; Barr and White 1998a). In addition, radiometric dating has shown that the volcanic and plutonic rocks in the Kingston belt are Silurian in age (Doig *et al.* 1990; McLeod *et al.* 1994; M. McLeod, unpublished data), and not Precambrian as earlier assumed (e.g., Rast 1979; O'Brien 1976; McCutcheon and Ruitenberg 1987; Dostal and McCutcheon 1990).

This paper is a progress report of an ongoing investigation of the Kingston terrane, begun in 1996 and involving both mapping and petrological studies. A preliminary map of the northeastern part of the terrane, from Highway 7 northeast through the Kingston Peninsula, was published previously (Barr and White 1998a). Mapping in 1998 covered the southwestern part of the terrane from Highway 7 southwest to Beaver Harbour (Barr and White 1998b). The present report provides an overview of lithologic units, structural features, and petrochemistry of igneous units in the Kingston terrane in the Kingston Peninsula-Beaver Harbour map area (Figure 1). It expands on the coverage but does not change significantly the conclusions in an earlier report that focused on the southwestern part of the Kingston Peninsula (Barr *et al.* 1997).

## GEOLOGICAL SETTING

On its southeastern margin, the Kingston terrane is in faulted contact with mainly Precambrian rocks of the Brookville terrane (Figure 1). The boundary is marked by a brittle fault (Kennebecasis fault) in the northeast, but to the southwest in the area of the Pocologan mylonite zone, the nature of the boundary becomes less clear. The protoliths of mylonitic rocks in the Pocologan area are difficult to interpret, but our preliminary assessment is that mylonite is developed mainly, if not entirely, in Precambrian rocks of



the Brookville terrane, not in Silurian rocks of the Kingston terrane. Hence, the boundary is inferred to be a brittle fault, located northwest of the zone of predominantly mylonitic rocks, protoliths of which may be part of the Green Head Group, Red Head granitoid suite, and perhaps metavolcanic rocks of the Brookville terrane (Figure 1).

On its northwestern margin, the Kingston terrane is in faulted contact at the Belleisle fault (Garnett and Brown 1973) with rocks of the New River terrane (Johnson and McLeod 1996). Along the northwestern margin of the Kingston Peninsula, volcanic and sedimentary rocks of the Long Reach Formation occur adjacent to the fault (McCutcheon and Ruitenberg 1987). Although also Silurian in age based on fossil evidence (Boucot *et al.* 1966), the Long Reach Formation is unmetamorphosed and relatively undeformed, in contrast to the rocks of the Kingston terrane (Barr *et al.* 1997). Adjacent to the Long Reach Formation in the Kingston Peninsula are Neoproterozoic volcanoclastic rocks of the Belleisle Bay Group (U-Pb zircon age of ca. 555 Ma; M. McLeod, unpublished data). The Long Reach Formation appears to be faulted out to the southwest, and Neoproterozoic volcanoclastic and varied granitoid rocks occur against the faulted margin of the Kingston terrane (Johnson and McLeod 1996). Granitoid and volcanoclastic rocks of the New River terrane are protomylonitic and cataclased adjacent to the Belleisle fault in the Seven Mile Lake area. In contrast, rocks of the Kingston terrane do not appear to be much deformed, and sedimentary structures are well preserved in outcrops around the southern shore of Seven Mile Lake.

Hence, our observations indicate that the present margins of the Kingston terrane on both the southwest and northeast are brittle faults.

## ROCK UNITS OF THE KINGSTON TERRANE

### *Bayswater Group*

Barr *et al.* (1997) and Barr and White (1998a) combined the Williams Lake and Bayswater volcanics of McLeod *et al.* (1994) into the Bayswater Group. A Silurian age is indicated by U-Pb (zircon) dates of ca. 434 Ma from a rhyolitic lithic-crystal tuff in the Kingston Peninsula (M. McLeod, unpublished data), and by dates of ca. 438 Ma (McLeod *et al.* 1994) and  $436 \pm 2$  Ma (Doig *et al.* 1990) from the Centreton and Sand Point plutons, respectively (Figure 1). These plutons are interpreted to be essentially comagmatic with the Bayswater Group.

On a preliminary basis, the Bayswater Group is divided into six units, which may be given formation status after mapping has been completed. The units are best exposed in the Kingston Peninsula, where the terrane is widest and less dominated by granitoid plutonic rocks than in the southwest (Figure 1). Although younging direction criteria are sparsely preserved, scattered occurrences of graded bedding and cross-bedding in minor epiclastic units indicate that the sequence youngs consistently to the northwest. Contacts between units appear to be gradational. The rocks are metamorphosed to upper greenschist facies and typically foliated (see section on Structure and Metamorphism), but primary igneous or sedimentary features are generally recognizable, and the rocks are named according to the inferred protolith characteristics.

The Bayswater Group has been intruded by abundant mafic (amphibolite) sheets, described separately in a subsequent section.

**Unit SB<sub>mt</sub>** occurs in a narrow belt adjacent to the Kennebecasis fault in the northeastern part of the Kingston Peninsula (Figure 1). Rocks typical of this unit are well exposed in brooks near Peekaboo Corner, and in road cuts on the steep southern margin of the Kingston terrane near Central Norton (Figure 1). The rocks are mainly basaltic to andesitic lithic and lithic-crystal lapilli tuff. Dominant minerals are sodic plagioclase, chlorite, and epidote, and clasts are mainly andesitic. Dacitic lithic lapilli tuff with felsic clasts is a minor component.

**Unit SB<sub>n</sub>** is a major unit that can be traced from the Peekaboo Corner area southwest along the terrane to Beaver Harbour (Figure 1). In the Kingston Peninsula, it corresponds to unit SB<sub>1</sub> of Barr *et al.* (1997). Rocks in the unit are mainly grey rhyolitic to dacitic lithic to lithic-crystal lapilli tuff. Welded and flow-banded textures are locally preserved. Lithic clasts comprise 50 to 90% of most samples, vary in colour from dark grey to pink or white, and represent both tuff and flow fragments. Most rocks also contain abundant small crystals of feldspar and aggregates of polygonal quartz. The groundmass is a fine-grained mixture of microcrystalline quartz and feldspar, with variable amounts of muscovite, chlorite, epidote, and biotite. Andesitic lithic tuff, thin-bedded tuffaceous siltstone, and mica-rich phyllite are minor components of the unit.

**Unit SB<sub>n</sub>** (equivalent to unit SB<sub>2</sub> of Barr *et al.* 1997) can be traced through the Kingston Peninsula and Highway 7, but appears to be cut off by the West Branch Reservoir pluton (Figure 1). It consists dominantly of rhyolitic crystal lapilli tuff, laminated ash tuff, and possibly felsic flows. Lithic clasts are not as abundant as in unit SB<sub>n</sub>. Crystals are mainly of plagioclase, with minor polygonal quartz, and rare K-feldspar. The groundmass is generally composed of cryptocrystalline quartz and feldspar; foliated samples also contain muscovite, chlorite, and biotite. Evidence of relict ignimbritic flow banding, marked by alternating cryptocrystalline and fine-grained layers, is common. Locally some layers contain spherulites. Unit SB<sub>n</sub> also includes rare buff to rusty brown phyllitic layers, similar to those in unit SB<sub>n</sub>.

**Unit SB<sub>n</sub>** (unit SB<sub>1</sub> of Barr *et al.* 1997) consists dominantly of dacitic to rhyolitic lithic-crystal and crystal lapilli tuff. Excellent exposures of the unit occur along the shore of Loch Alva, and on Highway 7 (Figure 1). In contrast to units SB<sub>n</sub> and SB<sub>n</sub>, the clasts generally consist of pink and white dacitic to rhyolitic ash tuff and flow fragments that commonly display aligned microlites of plagioclase and locally preserve spherulitic textures. Thin agglomerate layers with white-weathered rhyolitic clasts up to 30 cm in diameter occur locally. Crystals in the tuff are plagioclase, K-feldspar, and quartz. Andesitic lapilli tuff layers of variable thickness are a minor component. These andesitic tuffs differ from those in unit SB<sub>n</sub> in having small (<0.5 mm), euhedral crystals of amphibole. Unit SB<sub>n</sub> also includes tuffaceous siltstone horizons similar to those in unit SB<sub>n</sub>, and interbedded brown phyllitic to schistose pelitic rocks. Rare garnet forms tiny euhedral grains associated with biotite-rich layers.

**Unit SB<sub>n</sub>** occurs at the northeastern margin of the Kingston Peninsula (Figure 1), and may be the lateral equivalent of unit SB<sub>n</sub>. However, it is assigned to a separate unit because it is generally more rhyolitic than unit SB<sub>n</sub>. Crystal tuff or rhyolitic flows with variably abundant plagioclase crystals are characteristic.

**Unit SB<sub>mv</sub>** (unit SB<sub>3</sub> of Barr *et al.* 1997) consists of basaltic to andesitic flows, lithic to lithic-crystal lapilli tuff, laminated tuffaceous siltstone, wacke, and black slate. Flows consist of flow-aligned microphenocrysts of plagioclase in a pilotaxitic groundmass of plagioclase microlites and fine-grained actinolite and chlorite. Small flattened amygdules are filled with epidote, chlorite, or albite. Mafic tuffs in unit SB<sub>mv</sub> contain mainly clasts of porphyritic basalt and andesite. Unit SB<sub>mv</sub> also includes dacitic crystal-lithic lapilli tuff

and flows, characterized by abundant small crystals of white, euhedral albitized plagioclase and rare quartz. Epiclastic rocks (siltstone, wacke, and black slate) contain abundant biotite and muscovite, and are interlayered with tuff. Unit SB<sub>mv</sub> is well exposed around the southern shoreline of Seven Mile Lake, where primary sedimentary structures, including soft-sediment deformation, graded bedding, and cross-bedding, are well preserved in epiclastic rocks.

### ***Granitoid plutons***

Five elongate plutons form the core of the Kingston terrane (Figure 1). Two of the plutons (Sand Point and Centreton) were previously mapped and named (O'Brien 1976). The West Branch Reservoir, Bradley Brook, and Redden Brook plutons are new units named during the present study. The West Branch Reservoir pluton constitutes most of the southwestern part of the terrane (Figure 1). The plutons are heterogeneous, with abundant screens of volcanoclastic rocks which cannot be separated into mappable units. Like the host volcanic rocks, the plutons are intruded by abundant mafic (now amphibolite) sheets.

The plutonic rocks are mostly varied fine-grained aphyric to porphyritic granite. Medium-grained varieties with abundant interstitial granophyre occur more rarely. In many outcrops, the granite is difficult to distinguish from felsic volcanic rocks of the Bayswater Group, except that the granite is more homogeneous in appearance. The fine-grained granite is weakly to moderately foliated. Porphyritic varieties contain plagioclase and sanidine phenocrysts. Small flakes of biotite, in many samples accompanied by blue-green amphibole, are minor components, and accessory minerals include titanite, apatite, zircon, magnetite, and rare allanite. Albitization is widespread, especially in the Centreton and Sand Point plutons, with albite replacing both K-feldspar and originally more calcic plagioclase.

Areas of dark grey to black, medium- to coarse-grained monzodiorite and diorite, intruded by small granitic dykes, occur locally near the margins of the Centreton and West Branch Reservoir plutons.

Although contacts with the adjacent volcanic units are generally not exposed, in several areas a textural change from fine-grained porphyritic to progressively coarser grain size can be traced from near the contact toward the interior of the pluton. Adjacent to the West Branch Reservoir pluton, sheets of granite, mainly of the porphyritic variety, are abundant in the Bayswater Group.

### ***Mafic sheets***

Concordant mafic sheets up to a few metres in width are present in many outcrops in the Kingston terrane. In the Kingston Peninsula, they were termed "basic sill swarms" by O'Brien (1976). However, subsequent workers reported the presence of both mafic and felsic dykes and referred to them as the Kingston complex (Currie 1984; Eby and Currie 1993; Nance and Dallmeyer 1993), Kingston Dyke Swarm (McCutcheon and Ruitenberg 1987), or Kingston Dyke Complex (McLeod *et al.* 1994). Observations during the present study showed that screens between mafic sheets are volcanic or granitoid rocks, not felsic dykes, and that the mafic sheets invariably display chilled margins against the host rocks, or against one another in composite sheets. Although they locally cross-cut primary layering in the host rocks, most sheets are parallel to the near-vertical structures (layering and/or foliation) in their host rocks (see section on Structure and Metamorphism below) and hence could be termed sills, rather than dykes. We use the less specific term "sheet" for these bodies, because their original orientation at the time of emplacement is uncertain.

The mafic sheets in the Kingston terrane consist mainly of plagioclase and amphibole, and hence are termed amphibolite. They differ from dykes in the adjacent New River and Brookville terranes, which

contain secondary minerals such as chlorite and epidote, but are not metamorphosed to amphibolite (personal observations; White 1995). The age of the dykes in the Kingston terrane is constrained by the ca. 435 Ma ages of the host volcanic and plutonic rocks, and by  $^{40}\text{Ar}/^{39}\text{Ar}$  ages of ca. 420 to 390 Ma (but mainly ca. 410 Ma) for hornblende from sheets in the Kingston Peninsula through Beaver Harbour area (Nance and Dallmeyer 1993). Nance and Dallmeyer (1993) interpreted the dates to represent cooling ages after greenschist to lower amphibolite facies metamorphism, but to approximate the time of metamorphism because of the relatively high closure temperature of amphibole. Hence, they were emplaced after ca. 435 Ma but had been regionally metamorphosed by ca. 420 Ma.

The mafic dykes vary widely in texture, but no systematic pattern of textural variations through the terrane was noted. Most abundant are dykes with fine- to medium-grained intergranular textures, composed dominantly of subhedral plagioclase laths and interstitial amphibole and magnetite. A second type is dominated by medium- to coarse-grained amphibole and epidote, with interstitial plagioclase and quartz. Porphyritic dykes, with plagioclase phenocrysts, occur more rarely. The dominant amphibole variety is pleochroic from green to blue-green, and is of magnesiohornblende composition, but in most samples it is partly altered to actinolite. Biotite has partially replaced hornblende in many samples. In some samples, plagioclase retains relict igneous compositions and is zoned from labradorite cores to andesine, oligoclase and albite in outer parts. In many samples, albite forms clear rims around partly saussuritized cores.

## STRUCTURAL GEOLOGY AND METAMORPHISM

Regional deformation in the Kingston terrane was accompanied by upper greenschist facies metamorphism and the development of moderate to strong phyllitic to locally schistose or slaty foliation. Peak syntectonic metamorphic mineral assemblages appear to be albitic plagioclase + muscovite + biotite + epidote  $\pm$  blue-green amphibole in felsic volcanic and plutonic rocks, blue-green amphibole + quartz + epidote + biotite in mafic volcanic rocks and sheets, and muscovite + biotite  $\pm$  epidote  $\pm$  garnet in epiclastic rocks. Chlorite and actinolite appear to be retrograde. The foliation is defined by preferred orientation of muscovite, biotite, and amphibole (the latter two minerals partially replaced by chlorite and/or actinolite), and by elongate quartz-feldspar aggregates. In tuffaceous rocks, clasts generally are flattened parallel to tectonic foliation. The foliation is less well developed in the plutons, but marked by elongate quartz-feldspar aggregates and scattered aligned biotite flakes.

The foliation is typically subparallel to primary layering in the Bayswater Group and to mafic sheet orientations. In the southwestern part of the terrane (southwest of Highway 7 to Beaver Harbour) average bedding orientation (Figure 2a), foliation (Figure 2b), and sheet orientation (Figure 2c) are ca. 041–045° and vertical. In the northeastern part of the terrane (Highway 7 northeast through the Kingston Peninsula), average bedding orientation (Figure 2a), foliation (Figure 2b), and sheet orientation (Figure 2c) are ca. 020–022° and vertical. The parallelism of primary layering, foliation, and mafic sheet orientation suggests that both bedding and mafic sheet orientations have been transposed into the foliation plane, resulting in the sill-like appearance of the mafic sheets.

Primary layering and foliation commonly produce a steep intersection lineation, typically marked by colour streaks or small parallel ridges on the foliation planes. In lapilli tuff, the lineation is marked by elongate clasts. The orientation of the intersection lineation throughout the terrane forms a well defined cluster with an average orientation of 040°/82° (Figure 2d). A parallel intersection lineation is also developed near the chilled margins of some mafic sheets where the foliation is well developed. However, toward

## Domains

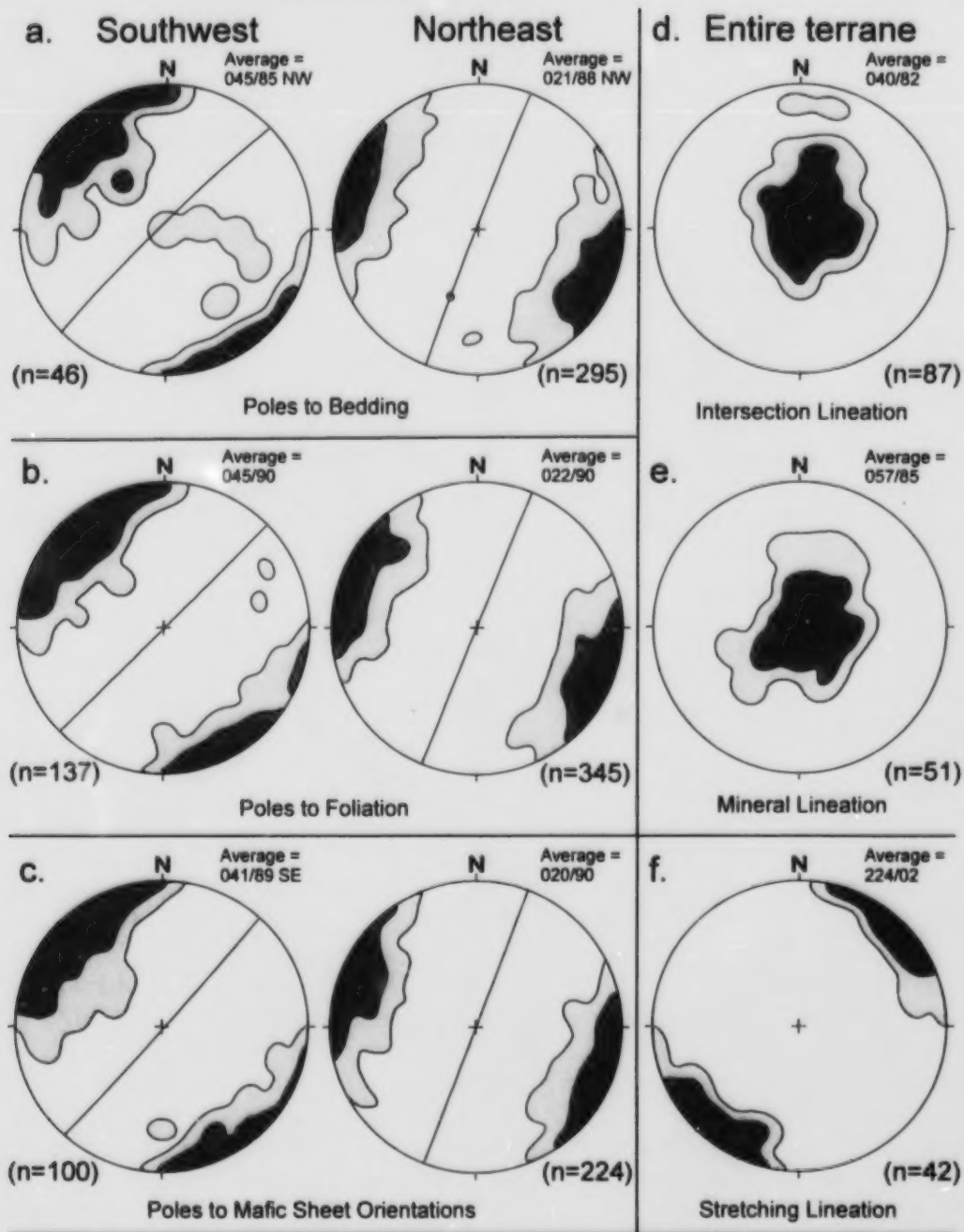


Figure 2. Stereoplots of structural data from the study area, as described in the text. Note that intersection and mineral lineation measurements (d, e) are from Kingston terrane units only (Bayswater Group and associated plutons and mafic sheets), whereas stretching lineations (f) are from the Pocologan mylonite zone.

the interior of some sheets a mineral lineation becomes more prominent that is typically defined by elongate hornblende. This mineral lineation is steep and similar in orientation to the intersection lineation (Figure 2e).

The lack of minor folds and the subparallel relationship of foliation, bedding, and sheet orientations suggest that the Bayswater Group may have been isoclinally folded (e.g., O'Brien 1976). However, this interpretation does not adequately account for the steep intersection and mineral lineations, and the consistent northwesterly younging directions. An alternative explanation is that the rocks were not folded but instead tilted and compressed, thus explaining the nonrepetition of the linear map units and the lack of minor folds.

Our data do not show evidence for the previously reported sigmoidal distribution of mafic dykes, or for gradual change in orientation of the lineation from horizontal near the margins of the terrane to vertical in the centre of the terrane, as suggested previously (Garnett and Brown 1973; Schreckengost and Nance 1996). The subhorizontal lineation reported by earlier workers (e.g., Nance and Dallmeyer 1993) was not observed in units of the Kingston terrane, but is present in units interpreted to be part of the adjacent Brookville terrane (Green Head Group? and Red Head granitoid rocks) in the West Branch Reservoir–Pocologan area (Figure 2f). This area is part of the Pocologan mylonite zone (Rast and Dickson 1982; Park *et al.* 1994). In the area mapped during the present study, this zone consists predominantly of L tectonites, although locally L–S tectonites are developed. The zone strikes northeast and dips steeply to the southeast, and has a well developed subhorizontal stretching lineation trending northeast–southwest (Figure 2f). It is typically defined by augen of feldspar and quartz and gives a consistent dextral, strike-slip sense of shear parallel to L (e.g., Rast and Dickson 1982; Leger and Williams 1986; Park *et al.* 1994). Some previous workers considered the Pocologan mylonite zone to be part of the Kingston terrane, and interpreted dyke orientation to indicate sinistral transpression later overprinted on the margins by dextral shear (e.g., Nance 1987; Nance and Dallmeyer 1993; Schreckengost and Nance 1996). Leger and Williams (1988) and Park *et al.* (1994) argued that the Kingston terrane is pervasively deformed with a dextral strike-slip movement throughout. However, Rast and Dickson (1982) suggested that mylonite is developed in the Green Head Group and related rocks, an interpretation more consistent with the present study.

## GEOCHEMISTRY

Approximately 110 samples from igneous units in the Kingston terrane have been analyzed for major and selected trace elements as part of the present study. Analyses were done mainly by standard X-ray fluorescence (XRF) techniques at the Regional Geochemical Centre, Saint Mary's University, Halifax, or by inductively coupled plasma-mass spectroscopy (ICP-MS) at Memorial University of Newfoundland. These new data have been combined with previously published analyses from Dostal and McCutcheon (1990) (2 analyses from unit SB<sub>mv</sub>) and Eby and Currie (1993) (5 samples from unit SB<sub>fx</sub> of the Bayswater Group, 6 samples from the Sand Point Pluton, and 13 samples from mafic dykes). Only an overview of the geochemical data is presented here, with a more detailed assessment of the data to be published elsewhere.

### *Bayswater Group*

The volcanic rocks of the Bayswater Group are represented by a total of 43 analyses, mainly from fine-grained crystal tuff and flow samples. The dominantly felsic composition of the rocks is reflected in the data; only seven samples (from units SB<sub>mt</sub>, SB<sub>mv</sub>, and SB<sub>n</sub> in the Beaver Harbour area) are mafic, with

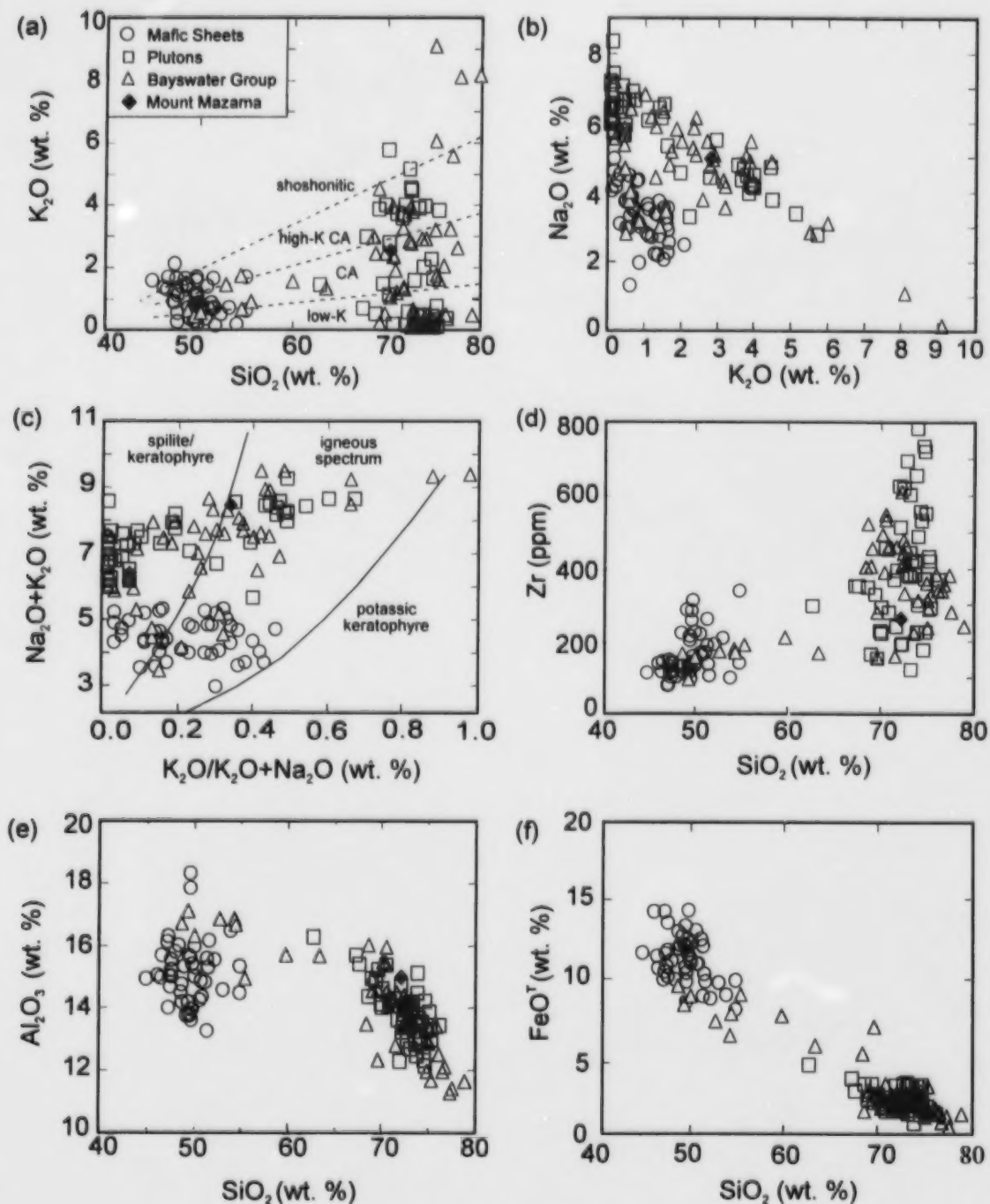


Figure 3. Diagrams to illustrate chemical variations in igneous rocks in the study area. (a)  $K_2O$  vs.  $SiO_2$ , with fields from Middlemost (1975); CA—calc-alkalic. (b)  $Na_2O$  vs.  $K_2O$ . (c)  $Na_2O+K_2O$  vs.  $K_2O/(K_2O+Na_2O)$ , with fields from Hughes (1973). (d) Zr vs.  $SiO_2$ . (e)  $Al_2O_3$  vs.  $SiO_2$ . (f)  $FeO^T$  vs.  $SiO_2$ . A typical calc-alkalic rhyolite from a continental arc (Mount Mazama, Crater Lake, Oregon; #846, Bacon and Druitt 1988) is shown for comparison on this and subsequent figures. Data are from the present study (110 analyses), Eby and Currie 1993 (24 analyses), and Dostal and McCutcheon 1990 (2 analyses).

SiO<sub>2</sub> contents ranging from 49 to 55%. The bulk of the samples have SiO<sub>2</sub> contents between 68 and 79%, and only two samples have intermediate compositions (Figure 3a). Effects of alteration and/or metamorphism are reflected in a wide variation in abundance of typically mobile components such as Na<sub>2</sub>O and K<sub>2</sub>O (Figure 3b, 3c). The Na<sub>2</sub>O and K<sub>2</sub>O contents in the felsic rocks show strong inverse correlation (Figure 3b), mainly resulting from sodic alteration (Figure 3c). Even the generally less mobile elements such as Zr (Figure 3d), show a wide range in the felsic samples and scattered correlation with Na<sub>2</sub>O (not shown), and hence may not be reliable indicators of their original compositions.

Mafic samples show less variation in these elements than felsic samples (e.g., Figure 3d). Relatively low Zr/TiO<sub>2</sub> and Nb/Y ratios, which are less likely to have been disturbed than absolute abundances (e.g., Winchester and Floyd 1977), indicate that the suite is subalkalic (Figure 4a, 4b). On tectonic setting discrimination diagrams for mafic rocks, the mafic samples plot mainly in the calc-alkalic basalt field (Figure 5a) or the overlapping volcanic-arc basalt/within-plate tholeiite field (Figure 5b). The relatively high Al<sub>2</sub>O<sub>3</sub> contents in mafic samples (Figure 3e) and low FeO<sup>T</sup> contents (Figure 3f), as well as a decrease in FeO<sup>T</sup> with increasing FeO<sup>T</sup>/MgO ratio in most samples (Figure 6a), are also consistent with calc-alkalic affinity. However, the number of mafic samples is small and these interpretations are not considered to be definitive.

The number of felsic samples is larger, but the evidence for alteration noted above makes interpretation of the data difficult. The scatter is clear on the commonly used tectonic setting discrimination diagram for granitic rocks (Figure 6b), and on the TiO<sub>2</sub>-Zr diagram (Figure 6c). However, the bulk of the samples plot in the arc field on Figure 6c. A multi-element variation diagram for four samples in which an expanded suite of elements was analyzed by ICP-MS shows a pattern similar to that of calc-alkalic rhyolite from Mount Mazama, a continental margin volcanic arc, including the Ta and Nb depletion typical of volcanic-arc suites (Figure 6d).

### ***Granitoid rocks***

Forty-seven analyses from the West Branch Reservoir, Sand Point, Centreton, Bradley Brook, and Redden Brook plutons show that they are chemically similar to the felsic volcanic rocks of the Bayswater Group (Figures 3, 4 and 6), consistent with the interpretation that the plutons are the intrusive equivalents of the volcanic rocks. As in the volcanic rocks, Na<sub>2</sub>O and K<sub>2</sub>O show wide variation, and an inverse correlation reflecting the progressive replacement of K-feldspar by albite (Figure 3b). As noted by Barr *et al.* (1997), the Sand Point pluton has been most pervasively affected by this alteration. The plutonic samples show the same spread as the felsic volcanic rocks in elements such as Zr (Figure 3d), Rb, Y, and Nb (Figure 6b). On the multi-element variation diagram, plutonic samples show patterns similar to those of felsic samples from the Bayswater Group (Figure 6d). A volcanic arc signature is apparent, in spite of the degree of alteration.

### ***Mafic sheets***

Mafic sheets are represented by a total of 46 analyses, of which 13 from Eby and Currie (1993) represent sheets in two short sections along Highway 7. However, no systematic difference is apparent between Highway 7 samples and those of this study which represent sheets from throughout the study area from Beaver Harbour through the Kingston Peninsula. SiO<sub>2</sub> contents range from about 45 to 54% (Figure 3a), and the samples are subalkalic (Figure 4a, 4b). Compared to mafic samples from the Bayswater Group, they generally have lower Al<sub>2</sub>O<sub>3</sub> and higher FeO<sup>T</sup> (Figure 3e, 3f), and show a typical tholeiitic trend of increasing FeO<sup>T</sup> with increasing FeO<sup>T</sup>/MgO ratio (Figure 6a). They plot across field boundaries on the

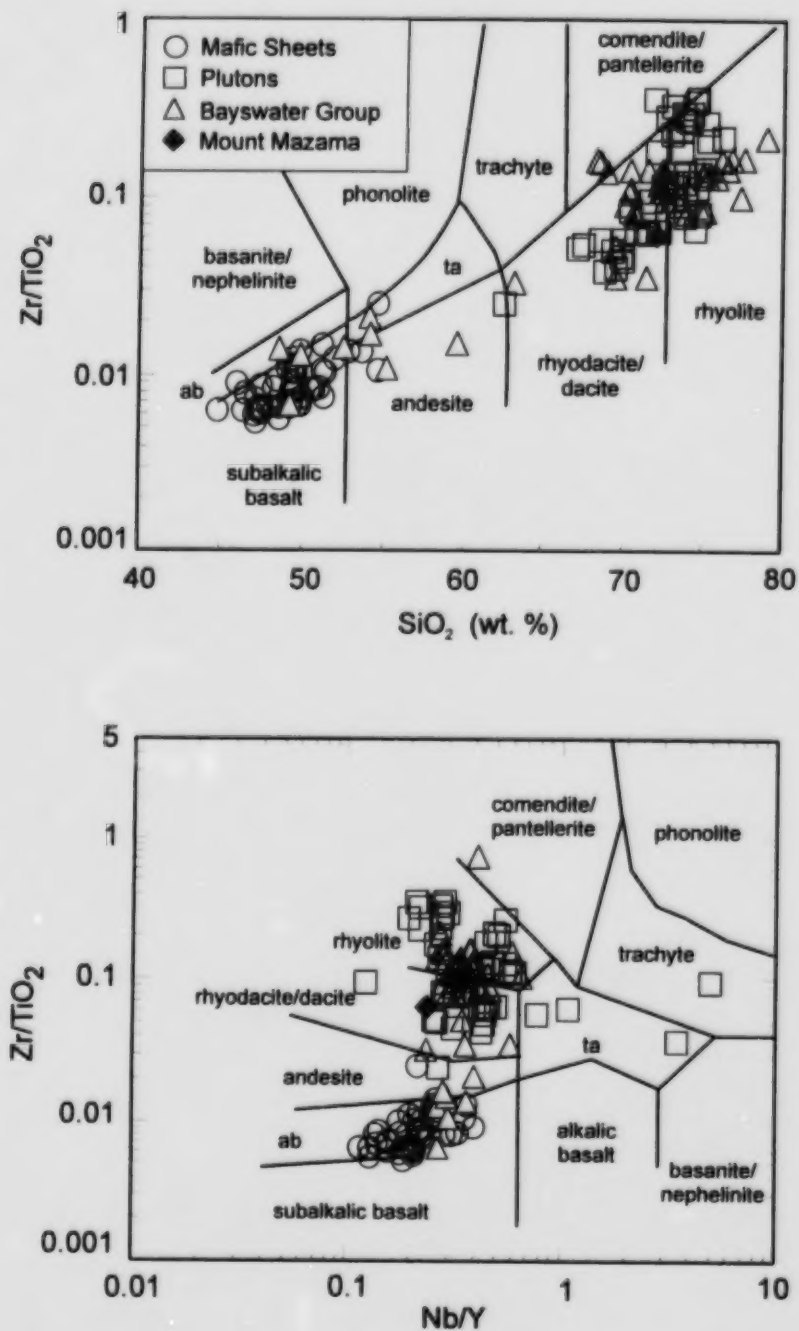


Figure 4. Plots of (a) Zr/TiO<sub>2</sub> vs. SiO<sub>2</sub> and (b) Zr/TiO<sub>2</sub> vs. Nb/Y to show subalkalic affinity of samples from the Kingston terrane (fields from Winchester and Floyd 1977). Data sources as in Figure 3. Abbreviations: ab—alkalic basalt; ta—trachyandesite.

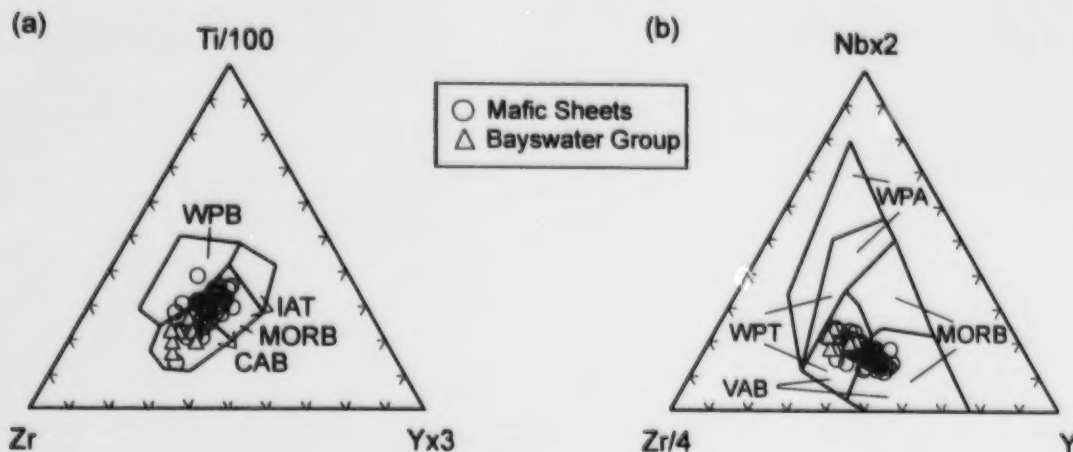


Figure 5. Mafic samples (less than 54%  $\text{SiO}_2$ ) plotted on tectonic setting discrimination diagrams from (a) Pearce and Cann (1973) and (b) Meschede (1986). Data sources are as in Figure 3. Abbreviations: WPB—within-plate basalt; IAT— island-arc tholeiite; MORB—mid-ocean-ridge basalt; CAB—calc-alkalic basalt; WPA—within-plate alkalic basalt; WPT—within-plate tholeiitic basalt; VAB—volcanic-arc basalt.

tectonic setting discrimination diagrams (Figure 5a, 5b), and the tectonic setting is not clear from these diagrams. However, they plot mainly in the within-plate field on the  $\text{TiO}_2$ –Zr diagram (Figure 6c).

Overall, the chemical data are interpreted to indicate that the sheets are tholeiitic and formed in a within-plate setting but with an arc influence. Such a setting is compatible with later extension in the arc environment represented by the Bayswater Group and associated plutons.

## ECONOMIC GEOLOGY

Exploration activity in the Kingston terrane has been limited, although many of the tuffaceous and plutonic rocks contain abundant pyrite and, locally, minor concentrations of base-metal sulphides. Geochemical results from this study show a range in metal values, especially in the mafic dykes, as exemplified by Cr and Zn (Figure 7a, 7b). Analyzed samples in the Kingston terrane contain up to 227 ppm Cu, 48 ppm Pb, 555 ppm Zn, 148 ppm Ni, and 400 ppm Cr. Additional pyrite-bearing samples collected for assay did not generally yield highly anomalous values of these metals or Au. Nevertheless, the volcanic arc setting of the volcanic and granitic rocks, combined with widespread alteration, suggests a potentially favourable environment for mineralization.

## CONCLUSIONS

The Kingston terrane consists mainly of Silurian volcanic and volcanoclastic rocks of the Bayswater Group and associated high-level granitic plutons. Based on their similarity in petrological characteristics, the volcanic and plutonic rocks are considered to be comagmatic, an interpretation supported by U–Pb dates from the northeastern part of the terrane. Petrochemical characteristics are consistent with origin in a continental margin volcanic arc. Mafic (amphibolitic) sheets are younger than both the volcanic and granitic rocks and, hence, the terrane should not be viewed as a bimodal dyke complex. The mafic sheets

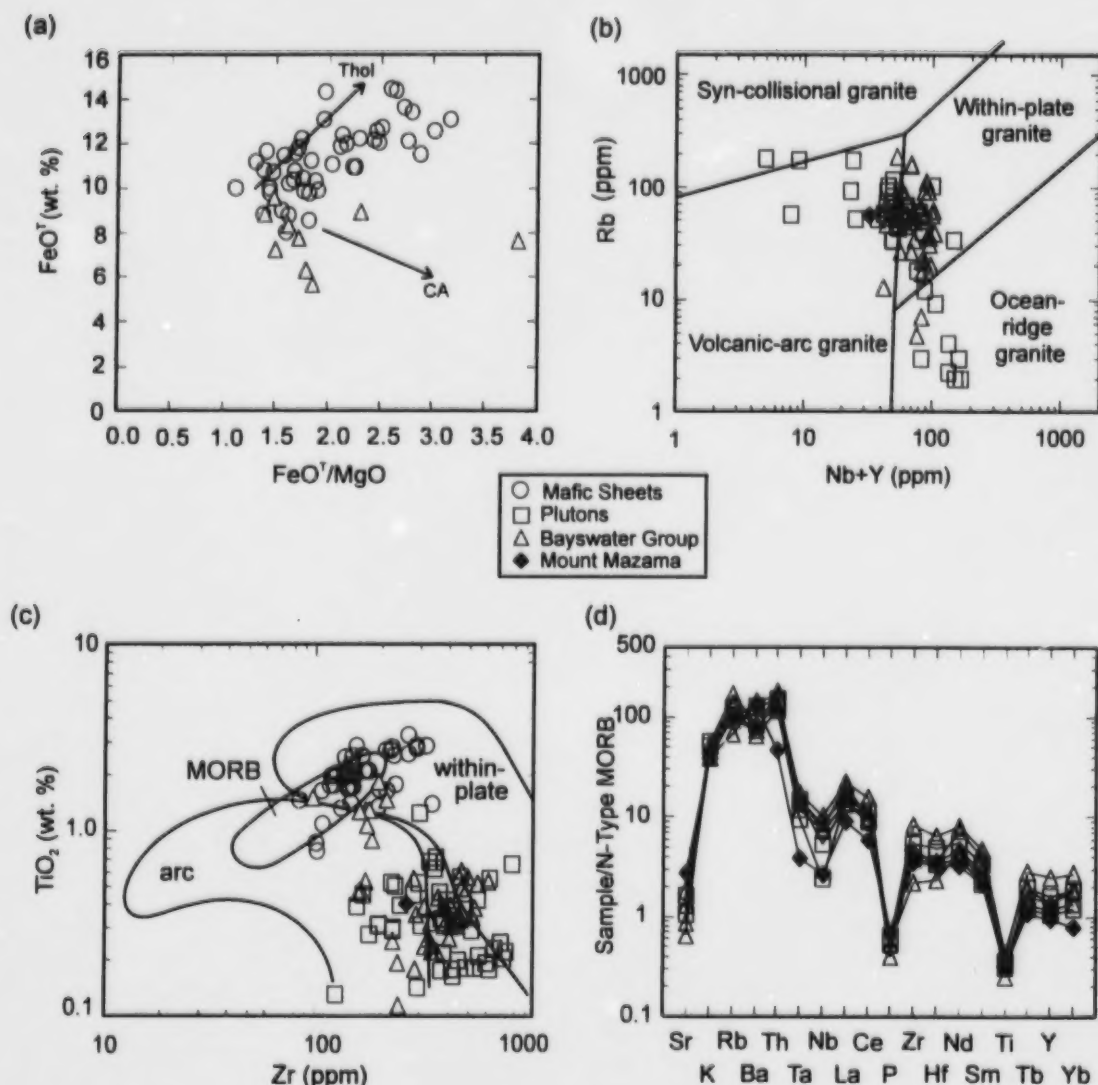


Figure 6. (a) Mafic and intermediate samples (<65%  $\text{SiO}_2$ ) plotted on a  $\text{FeO}^T$  vs.  $\text{FeO}^T/\text{MgO}$  diagram, with typical tholeiitic (Thol) and calc-alkalic (CA) trends from Miyashiro (1974). (b) Felsic samples (more than 65%  $\text{SiO}_2$ ) plotted on the Rb vs. Nb+Y tectonic setting discrimination diagram of Pearce *et al.* (1984). (c) Plot of  $\text{TiO}_2$  vs. Zr with fields for mid-ocean-ridge basalt (MORB), arc, and within-plate volcanic rocks from Pearce (1982). (d) Multi-element variation diagram comparing seven samples from the Bayswater Group and associated plutons to a continental volcanic-arc rhyolite from Mount Mazama as described in Figure 3. Data are normalized to Normal Mid-Ocean Ridge Basalt (N-MORB) from Sun and McDonough (1989).

and their host rocks were regionally metamorphosed and deformed at ca. 420 Ma. Brittle faults separate the Kingston terrane from Precambrian rocks of the now-adjacent Brookville and New River terranes, but the original location of the Kingston terrane relative to these older terranes is not known.

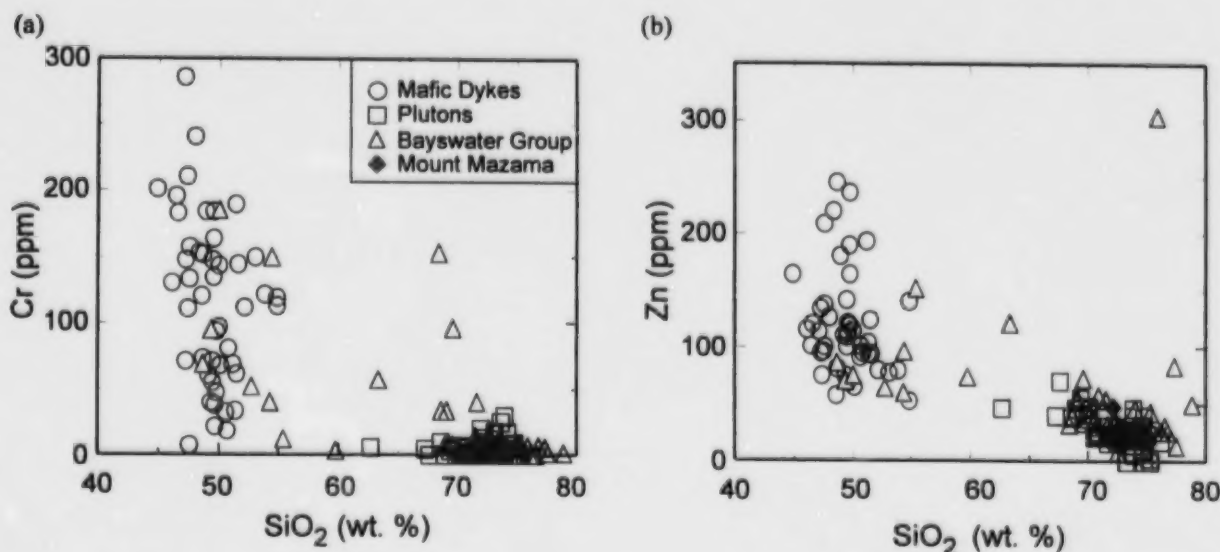


Figure 7. Plots of (a) Cr and (b) Zn against  $\text{SiO}_2$ , to illustrate the range in metal values in the analyzed samples. Data sources are as in Figure 3.

## ACKNOWLEDGEMENTS

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## **$^{40}\text{Ar}/^{39}\text{Ar}$ DATING OF DETRITAL MUSCOVITE FROM POST-VISÉAN (CARBONIFEROUS) SANDSTONES IN SOUTHEASTERN NEW BRUNSWICK †**

**S.C. Johnson**

New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch,  
P.O. Box 5040, Sussex, New Brunswick, CANADA E4E 5L2 (e-mail: scjohnson@gov.nb.ca)

JOHNSON, S.C. 1999.  $^{40}\text{Ar}/^{39}\text{Ar}$  dating of detrital muscovite from post-Viséan (Carboniferous) sandstones in southeastern New Brunswick. *In* Current Research 1998. Edited by B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 99-4, pp. 19-34.

In the west and central parts of the Maritimes Basin in New Brunswick and Nova Scotia, fluvatile strata overlying the Mabou Group are assigned to the Cumberland and Pictou groups. The constituent formations of the latter two groups in southeastern New Brunswick are, from base to top, the Boss Point, Grande Anse, Salisbury, Richibucto and Tormentine formations. The presence of abundant coarse-grained detrital mica and absence of highly quartzose sandstones in the Richibucto and Tormentine formations makes them unique from the underlying units.  $^{40}\text{Ar}/^{39}\text{Ar}$  dating of detrital muscovite from the Cumberland (Boss Point Formation) and Pictou (Richibucto and Tormentine formations) groups was utilized to determine if compositional changes in the sandstones were recording: (1) a lateral shift in the sediment source and/or (2) a vertically deeper source through time. Muscovite ages from seven samples ranged from Middle Devonian ( $390.7 \pm 3$  Ma) to Early Carboniferous ( $357.4 \pm 3.2$  Ma). The  $^{40}\text{Ar}/^{39}\text{Ar}$  analyses indicate that, based on age, no distinction can be made between detrital muscovites from the Cumberland Group and the Pictou Group and that the sediment provenance was reasonably stable throughout the Upper Carboniferous. However, the compositional differences among the sandstones remain a useful tool to delineate and correlate lithostratigraphic units.

Les chercheurs ont rattaché les strates fluviales recouvrant le groupe de Mabou dans les parties occidentale et centrale du bassin des Maritimes, au Nouveau-Brunswick et en Nouvelle-Écosse, aux groupes de Cumberland et de Pictou. Les formations constituantes de ces deux derniers groupes dans le sud-est du Nouveau-Brunswick sont, de la base au sommet: les formations de Boss Point, de Grande Anse, de Salisbury, de Richibucto et de Tormentine. La présence d'une quantité abondante de mica détritique à gros grain et l'absence de grès fortement quartzeux dans les formations de Richibucto et de Tormentine rendent celles-ci uniques par rapport aux formations sous-jacentes. On a eu recours à la datation à l' $^{40}\text{Ar}/^{39}\text{Ar}$  de la muscovite détritique des groupes de Cumberland (Formation de Boss Point) et de Pictou (formations de Richibucto et de Tormentine) pour déterminer si les modifications de la composition des grès avaient enregistré: 1) un déplacement latéral dans la source de sédiments ou 2) une source verticalement plus profonde au fil du temps. L'âge de la muscovite des sept échantillons prélevés variait du Dévonien moyen ( $390,7 \pm 3$  Ma) au Carbonifère précoce ( $357,4 \pm 3,2$  Ma). Les analyses à l' $^{40}\text{Ar}/^{39}\text{Ar}$  révèlent qu'on ne peut effectuer aucune distinction entre la muscovite détritique du groupe de Cumberland et celle du groupe de Pictou d'après l'âge et que la provenance des sédiments a été relativement stable tout au long du Carbonifère tardif. Les modifications de composition parmi les grès demeurent néanmoins un outil utile pour délimiter et corréler les unités lithostratigraphiques.

† New Brunswick Geological Surveys Branch ordinary budget.

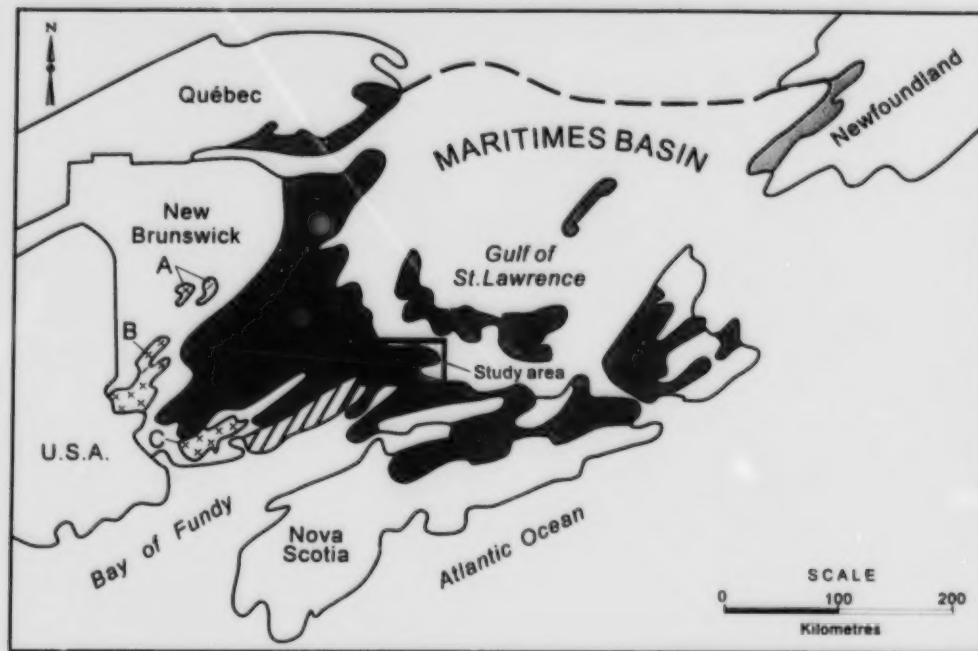


Figure 1. Regional location map illustrating the study area and showing the present day distribution of Late Devonian–Carboniferous rocks of the Maritimes Basin (shaded), Caledonia Highlands (hatched), Burnthill Granite suite (A), Pokiok Batholith (B), and Saint George Batholith (C).

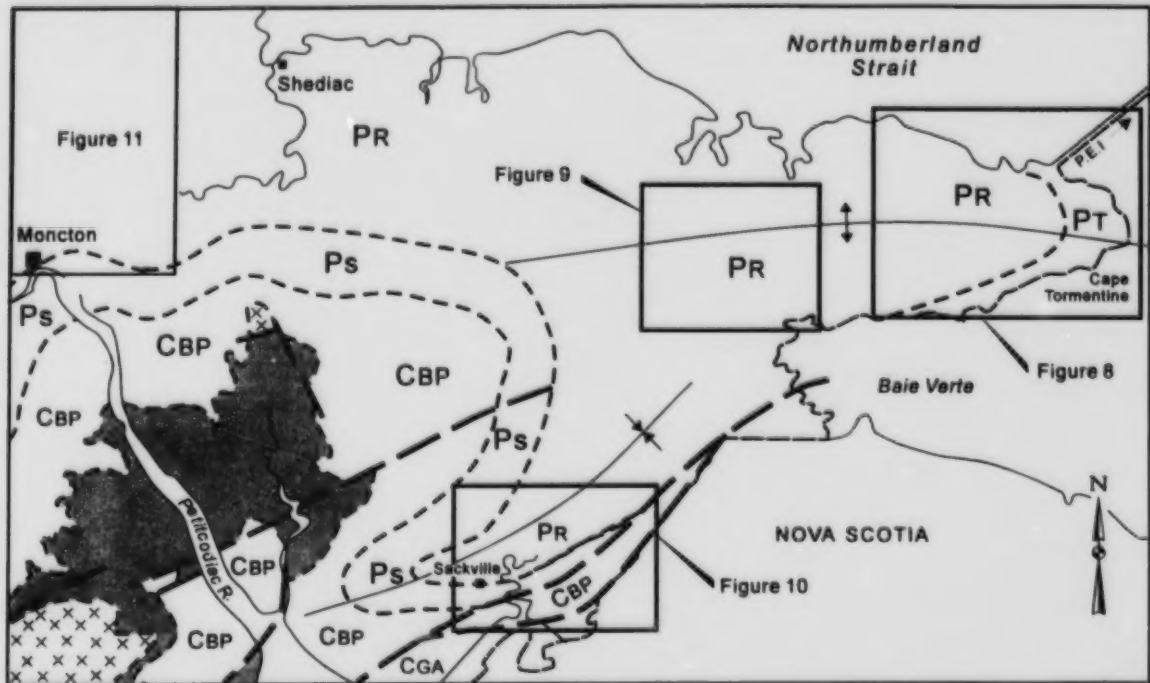
## INTRODUCTION AND PURPOSE

During the period 1994–1997, the author was involved in a mapping program to study mainly Upper Carboniferous rocks in southeastern New Brunswick. The project was funded by the federal NATMAP Magdalen Basin Project, which was initiated to investigate the stratigraphy, structure, basin development, energy and mineral resources of the Late Devonian to Permian Maritimes Basin (Figure 1). As part of this study in New Brunswick,  $^{40}\text{Ar}/^{39}\text{Ar}$  mineral ages for detrital muscovite were utilized in order to determine if there is a correlation between lithologically similar groups of rocks and sediment provenance. If a change in the sediment source area were responsible for recorded compositional differences within sandstones, the muscovite ages could potentially reflect this change. Sandstones from the Boss Point, Salisbury, Richibucto and Tormentine formations were collected for  $^{40}\text{Ar}/^{39}\text{Ar}$  dating. The Grande Anse Formation was considered to be part of the Salisbury Formation when this project began (Gussow 1953), and unfortunately, samples of the Grande Anse were not taken for dating. The two samples collected from the Salisbury Formation contained insufficient muscovite for analysis, even after re-collection; therefore, detrital muscovite ages for the Salisbury Formation are also not available. Detailed argon isotope incremental step heating data for the Boss Point, Richibucto and Tormentine formations are given in Table 1.

Table 1.  $^{40}\text{Ar}/^{39}\text{Ar}$  Incremental Step Heating Data.

Temp °C	$^{40}\text{Ar}/^{39}\text{Ar}$	$^{37}\text{Ar}/^{39}\text{Ar}$	$^{26}\text{Ar}/^{39}\text{Ar}$	Moles $^{39}\text{Ar}$	%Total	% $^{39}\text{Ar}$ RAD	K/Ca	Age (Ma)
SAMPLE AR-1: $J = 0.007513$								
770	49.472	0.08951	0.08984	8.0	1.7	58.3	5.5	353.7 ± 4.0
870	34.072	0.01608	0.01182	28.5	8.0	89.7	30.5	372.9 ± 3.7
950	31.872	0.03056	0.00453	60.7	12.7	95.7	18.0	370.2 ± 4.0
1010	31.183	0.02345	0.00278	78.6	18.4	97.3	20.9	370.8 ± 3.4
1085	31.021	0.02580	0.00215	80.4	18.8	97.9	19.0	370.8 ± 3.4
1145	30.831	0.00890	0.00156	78.6	18.0	98.5	55.1	370.6 ± 3.4
1210	30.875	0.00222	0.00096	88.8	18.5	99.0	220.7	370.8 ± 3.4
Fuse	30.970	0.00934	0.00193	57.4	12.0	98.1	52.5	371.0 ± 3.4
Total				479.0	100.0			370.5 ± 3.5
Plateau Age								376.7 ± 2.4
SAMPLE AR-2: $J = 0.007943$								
770	47.746	0.01195	0.08540	7.7	1.9	59.5	41.0	367.1 ± 8.2
870	32.858	0.08556	0.01455	24.3	5.9	88.9	5.7	368.7 ± 3.4
950	30.380	0.02884	0.00537	46.0	11.3	94.7	17.0	371.2 ± 3.4
1010	29.561	0.00164	0.00290	84.1	15.7	97.0	299.8	370.0 ± 3.4
1085	29.333	0.01957	0.00209	65.1	15.9	97.8	25.0	370.5 ± 3.5
1145	29.181	0.01807	0.00190	81.3	15.0	98.0	30.5	369.4 ± 3.4
1210	28.946	0.00400	0.00123	84.2	20.6	98.7	122.5	368.9 ± 3.3
Fuse	29.303	0.00700	0.00219	56.5	13.8	97.7	70.0	369.8 ± 3.4
Total				409.2	100.0			369.7 ± 3.4
Plateau Age								370.3 ± 3.3
SAMPLE AR-3: $J = 0.00783$								
770	226.800	0.09872	0.68603	9.0	2.2	10.5	5.0	309.1 ± 22.8
870	127.090	0.06310	0.33834	18.4	4.6	21.3	7.8	347.2 ± 10.8
950	78.396	0.02659	0.16926	32.7	8.1	36.2	18.4	361.9 ± 4.1
1010	56.836	0.01465	0.09639	69.5	17.3	49.9	33.4	361.5 ± 3.5
1085	55.946	0.02390	0.09363	63.9	15.9	50.4	20.5	359.7 ± 3.3
1155	62.149	0.04820	0.11412	55.3	13.7	45.7	10.2	362.4 ± 7.8
1230	61.674	0.01929	0.11266	63.6	15.8	48.0	25.4	361.9 ± 3.8
Fuse	53.404	0.03480	0.08454	89.8	22.3	53.2	14.1	362.4 ± 3.5
Total				402.4	100.0			359.8 ± 4.9
Plateau Age								361.5 ± 3.9
SAMPLE AR-4: $J = 0.007803$								
770	41.018	0.00176	0.03746	13.8	3.1	73.0	279.0	378.7 ± 6.5
870	29.242	0.02080	0.00524	47.2	10.8	94.7	23.6	352.8 ± 3.2
950	28.347	0.02783	0.00236	73.9	16.9	97.5	17.6	352.3 ± 3.8
1010	28.410	0.00102	0.00183	78.6	17.5	98.0	480.4	354.8 ± 3.2
1085	28.607	0.01573	0.00149	63.2	14.4	98.4	31.2	358.3 ± 3.3
1145	28.392	0.01811	0.00095	83.9	19.2	99.0	27.1	357.6 ± 3.2
1210	28.480	0.02992	0.00141	54.7	12.5	98.5	18.4	356.8 ± 3.2
Fuse	30.066	0.00247	0.00689	24.2	5.5	93.2	198.5	356.9 ± 3.4
Total				437.5	100.0			356.3 ± 3.4
Plateau Age								357.4 ± 3.2
SAMPLE AR-5: $J = 0.00796$								
770	101.450	0.07070	0.25252	12.4	2.8	26.4	6.9	349.1 ± 6.1
870	89.897	0.04156	0.14302	28.6	6.5	39.5	11.8	358.6 ± 4.0
950	51.762	0.01156	0.08026	60.4	13.7	54.1	42.4	363.3 ± 3.3
1010	51.908	0.02822	0.08125	68.1	15.5	53.7	17.4	361.7 ± 4.1
1085	57.477	0.03927	0.10046	67.4	15.3	48.3	12.5	360.4 ± 3.5
1145	61.891	0.01643	0.11512	57.4	13.0	45.0	29.8	361.3 ± 3.7
1210	53.110	0.01948	0.08524	93.6	21.3	52.5	25.1	361.9 ± 3.4
Fuse	75.403	0.03410	0.16160	51.8	11.8	38.7	14.4	358.7 ± 5.6
Total				439.6	100.0			360.8 ± 3.9
Plateau Age								360.8 ± 4.4
SAMPLE AR-6: $J = 0.007889$								
950	152.790	0.00317	0.41707	13.6	47.6	19.3	154.6	369.6 ± 8.3
Fuse	155.740	0.04215	0.42708	15.0	52.4	19.0	11.6	369.5 ± 9.4
Mean								369.6 ± 2.1
SAMPLE AR-10: $J = 0.007482$								
770	48.272	0.29158	0.05697	7.4	2.6	65.1	1.7	380.3 ± 11.3
870	36.405	0.00184	0.01379	16.6	5.8	88.8	265.9	389.7 ± 4.0
950	33.711	0.03048	0.00482	31.4	10.9	95.6	16.1	389.0 ± 3.5
1010	33.093	0.00658	0.00242	47.0	16.3	97.8	74.5	390.2 ± 3.5
1085	32.971	0.01452	0.00207	40.3	14.0	98.1	33.7	390.0 ± 3.5
1145	32.878	0.00920	0.00139	54.2	18.8	98.7	53.2	391.2 ± 3.5
1210	32.709	0.00870	0.00098	60.4	21.0	99.1	73.1	390.7 ± 3.6
Fuse	33.297	0.05022	0.00280	30.5	10.6	97.5	9.8	391.3 ± 3.6
Total				287.9	100.0			390.2 ± 3.8
Plateau Age								390.7 ± 3.0

\*For explanation of J value see Faure (1977)



### LEGEND

#### UPPER CARBONIFEROUS PICTOU GROUP

- PT** Tormentine Formation
- PR** Richibucto Formation
- Ps** Salisbury Formation

#### CUMBERLAND GROUP

- CGA** Grande Anse Formation
- CBP** Boss Point Formation

#### LOWER CARBONIFEROUS

- Pre-Cumberland Carboniferous strata
- Pre-Carboniferous

#### SYMBOLS

- Geological contact
- Fault
- Anticline
- Syncline

Figure 2. Geology map of southeastern New Brunswick with location of detailed sample site maps.

## GENERAL GEOLOGY

In southeastern New Brunswick, Carboniferous rocks that overlie Viséan to (?) Early Namurian strata of the Mabou Group are assigned to, in ascending order, the Boss Point, Grande Anse, Salisbury, Richibucto and Tormentine formations (Figure 2). The succession is generally flat lying to gently dipping and characterized by repetitive fluvial lithofacies. Due to the cyclical nature of the sedimentation, differences between lithological units are very subtle. Field observations indicate that medium-grained sandstones within the Richibucto and Tormentine formations are commonly highly micaceous and never highly quartzose. In contrast, the presence of very quartz-rich sandstones and rarity of micaceous sandstones distinguish the underlying formations. Johnson (1996) suggested that these findings have implications for the position of the Cumberland-Pictou group boundary in New Brunswick.

Historically, the Boss Point and overlying formations were included in the Petitcodiac Group by Wright (1922) and Norman (1932, 1941). Gussow (1953) reassigned the Salisbury and younger formations to the Pictou Group. Ryan *et al.* (1991) used lithologic criteria, such as the occurrence of coal-bearing strata, the relative amount of red and grey lithofacies, fine-coarse ratios and the degree of lateral facies variation to redefine the Cumberland and Pictou groups in the type section in Nova Scotia. Using their criteria, all of the post-Mabou Group Carboniferous strata in southeastern New Brunswick, except the Tormentine Formation, would be part of the Cumberland Group. Johnson (1996) utilized sandstone composition to determine natural relationships between the formations and argued that the base of the Pictou Group is more appropriately placed at the base of the Richibucto Formation. Giles and Utting (1999) suggested that a disconformity between the Salisbury Formation and the underlying Grande Anse and Boss Point formations, first proposed by Gussow (1953) and later Carr (1968), is regionally significant. If this is the case, and the Salisbury Formation is included in the Cumberland Group as advocated by Johnson (1996), a substantial disconformity would occur within the group. Critical to the interpretation of a regional unconformity at this boundary is the age of the strata within this interval and the nature of the contact between the Salisbury Formation and underlying rocks. Lithostratigraphic and palynostratigraphic studies of this stratigraphic interval are ongoing and at present this problem has not been resolved. For a full discussion of this problem see Johnson (1996) and St. Peter and Johnson (in prep).

## SANDSTONE PETROGRAPHY

To corroborate the field observation that sandstones with a high-quartz content were restricted to the Boss Point, Grande Anse and Salisbury formations, point counting of medium-grained sandstones was undertaken. As illustrated in Figures 3 and 4, all units exhibit a wide range of sandstone compositions; however, those with >75% quartz (quartz arenites, sublitharenites, and subarkoses) were found to be present only within the Boss Point, Grande Anse and Salisbury formations (Figure 3). Every one of the twenty-eight samples from the Richibucto and Tormentine formations contained <75% quartz (Figure 4). Petrographic examination of sandstone from the Salisbury Formation southwest of Moncton demonstrates that they can be extremely quartz rich (Figure 5).

The mica content of the sandstone is also diagnostic. In the sixteen samples point counted during this study, muscovite and minor biotite make up less than 1% of all clasts in the Salisbury and Grande Anse formations, 2–3 % of all clasts in the Richibucto and 2–8 % of the detrital content in the Tormentine Formation.

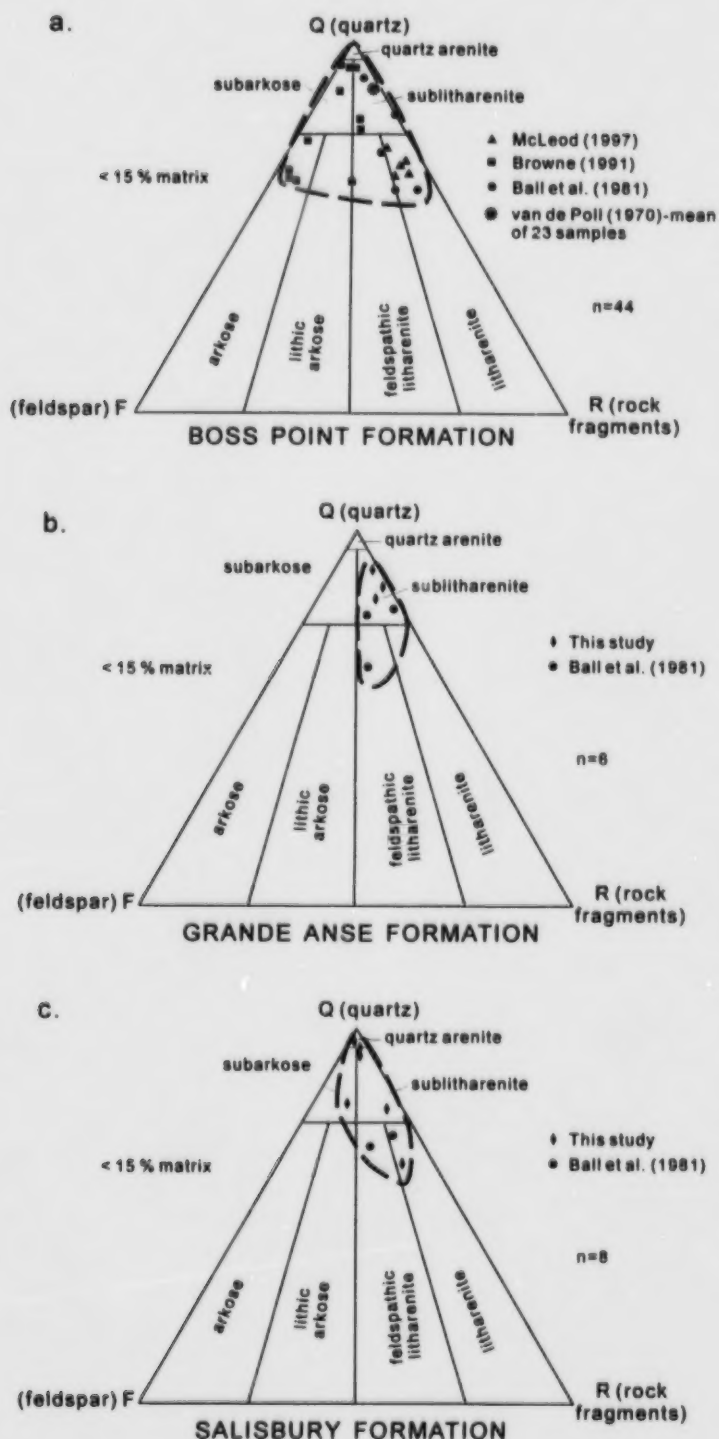


Figure 3. Ternary plot of medium-grained sandstones: (a) Boss Point Formation, (b) Grande Anse Formation, and (c) Salisbury Formation. The raw data of McLeod (1997) was recalculated to 100%. The classification diagram is after Folk (1974).

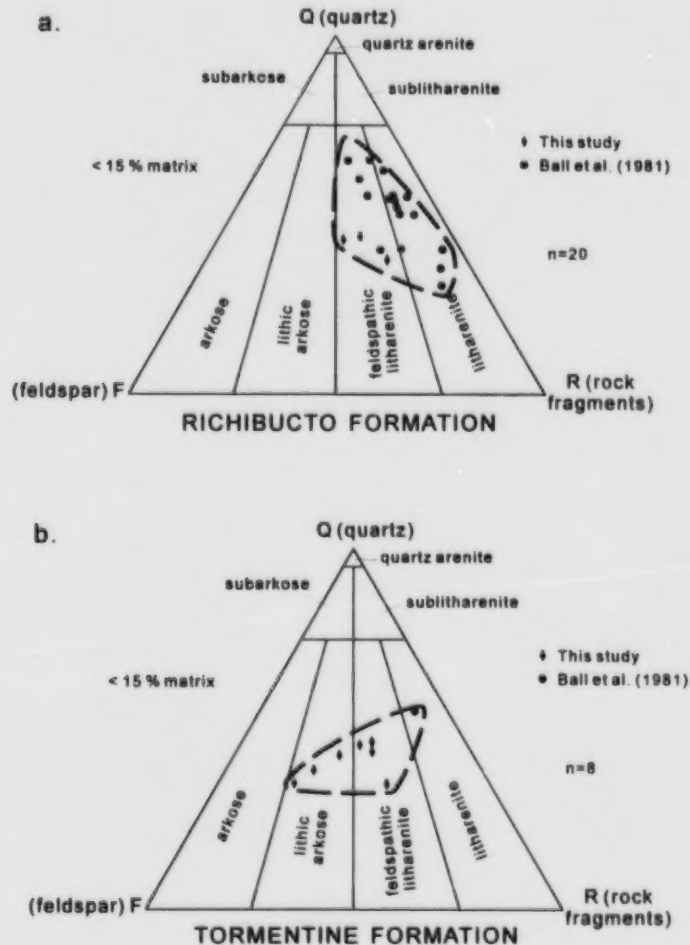


Figure 4. Ternary plot of medium-grained sandstones: (a) Richibucto Formation and (b) Tormentine Formation. The classification diagram is after Folk (1974).

Point counts for Boss Point Formation sandstones were compiled from several sources, including McLeod (1997), Browne (1991), Ball *et al.* (1981) and van de Poll (1970); therefore, quantitative data on muscovite was not available. Field estimates suggest that mica comprises a very low percentage of the detrital clasts in the Boss Point Formation. Additionally, visual estimates made in the field indicate that the mica content of Richibucto Formation sandstones can also be very high and are likely to have an upper range similar to the Tormentine Formation. Figures 6 and 7 show typical micaceous sandstones from the Richibucto and Tormentine formations, respectively.

## DATING METHOD

The  $^{40}\text{Ar}/^{39}\text{Ar}$  method, described by Faure (1977) and Dallmeyer (1979), is based on the production of  $^{39}\text{Ar}$  from  $^{39}\text{K}$  by a reaction during neutron irradiation. The theory and analytical techniques are generally

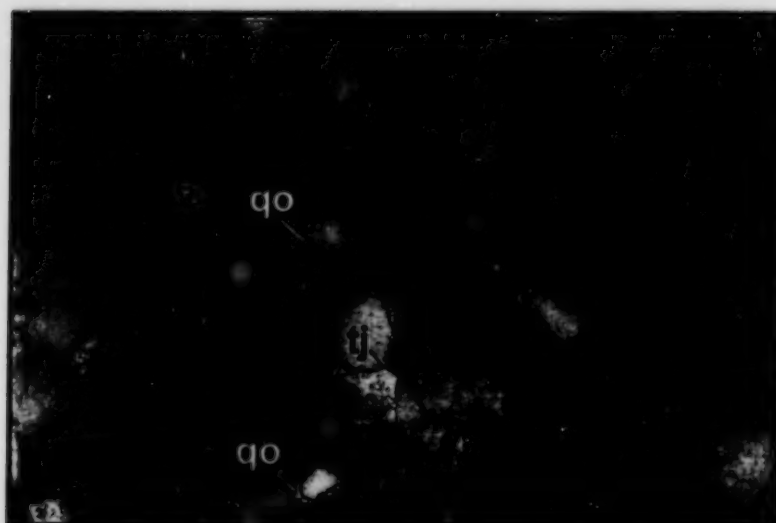


Figure 5. Subvolcanic litharenite from the Salisbury Formation southwest of Moncton. Pressure solution features such as triple junctions (tj) can be seen. Subvolcanic authigenic quartz overgrowths (qo) are abundant in this view. Vacuoles (v) in quartz indicate a hydro-thermal vein source for the quartz. The field of view is approximately 3 mm. Taken with partly crossed nichols.

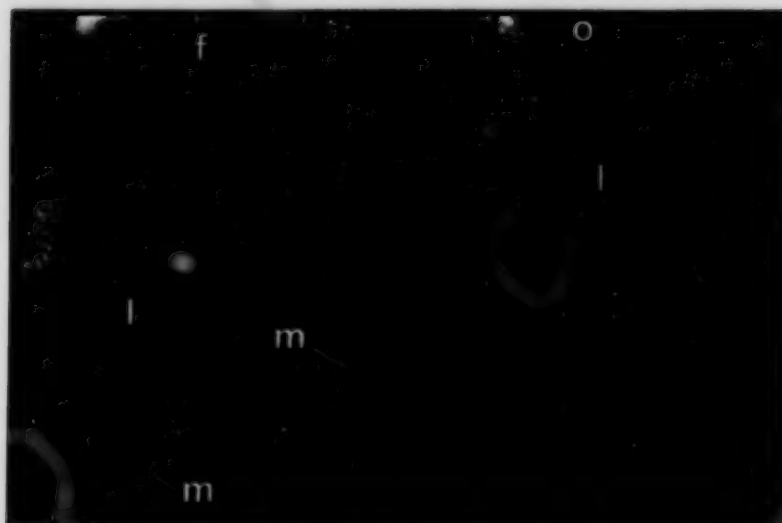


Figure 6. Feldspathic litharenite typical of the Richibucto Formation near Port Elgin (see Figure 9). Detrital grains of muscovite (m), feldspar (f), opaque iron-oxides (o), and quartz (q) are visible in this photo. The field of view is approximately 3 mm. Taken with partly crossed nichols.

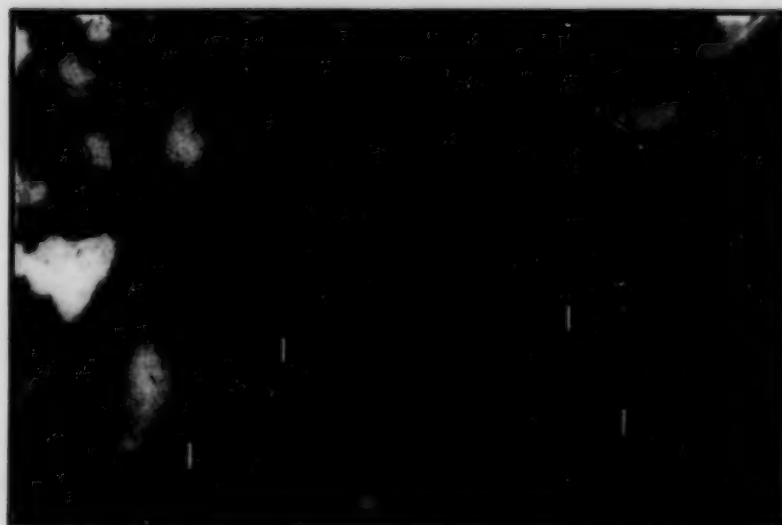


Figure 7. Lithic arkose of the Tormentine Formation near Cape Tormentine (see Figure 8). The rock has abundant muscovite (m), feldspar (f) and rock fragments (l). The field of view is approximately 3 mm. Taken with partly crossed nichols.

similar to those for K-Ar dating except that potassium is measured as a function of  $^{39}\text{Ar}$ . Argon is released from the irradiated sample in steps at increasing temperatures (incremental heating technique), thus a spectrum of dates can be calculated from the ratio of radiogenic  $^{40}\text{Ar}$  to neutron-produced  $^{39}\text{Ar}$  for each fraction. Total gas ages are calculated using the average of the ages weighted by the percent  $^{39}\text{Ar}$  released (% Total) within each heating increment after the complete release of all gases from the irradiated sample. The plateau ages have been computed by averaging the dates of the gas fractions that have reached a plateau, corresponding to the time elapsed since original cooling of the mineral (Faure 1977). Dr. Daniel Lux at the University of Maine at Orono conducted the analyses and provided the  $^{40}\text{Ar}/^{39}\text{Ar}$  thermochronologic data and release spectra diagrams.

## PREPARATION AND SAMPLE LOCATION

Ten samples were collected from locations in southeastern New Brunswick and submitted to the Technical University of Nova Scotia (TUNS) for mineral separation using standard techniques and then were upgraded further by manual separation with a binocular microscope. The muscovite separates were coarse-grained and alteration of the grains appeared to be minimal. Samples 95SJ AR-7 (Salisbury Formation), 95SJ AR-8 (Boss Point Formation) and 95SJ AR-9 (Salisbury Formation) contained insufficient muscovite for analysis and, therefore, are not described below.

**Sample 95SJ AR-1** was collected from a coastal exposure near Cape Bruin within Murray Beach Provincial Park (Figure 8). The sample comprised light grey-green, medium-grained, micaceous sandstone containing pebble lag deposits up to 30 cm thick. The sandstones are large-scale trough cross-bedded. ***Richibucto Formation.***

**Sample 95SJ AR-2** was collected from an exposure along the Northumberland Strait shore, approximately 3 km east of the Confederation Bridge to Prince Edward Island (Figure 8). The exposure comprises light red, fine- to medium-grained, calcareous, micaceous sandstone. Nearby, the sandstone contains numerous calcareous concretions and red mudstone intraclasts. ***Tormentine Formation.***

**Sample 95SJ AR-3** was collected along the shore of Baie Verte approximately 3 km west of Cape Spear (Figure 8). Greyish red, medium-grained sandstone overlies a thick lens of calcareous mudstone-clast conglomerate at this location. The sandstone is thin- to medium-bedded and moderately micaceous. ***Tormentine Formation.***

**Sample 95SJ AR-4** was collected from a small abandoned quarry immediately south of Highway 16, approximately 2 km west of Melrose (Figure 8). The sample consisted of grey, medium-grained sandstone containing carbonized plant fragments and finely disseminated manganese oxides. ***Richibucto Formation.***

**Sample 95SJ AR-5** was collected from an abandoned pit off a logging road between the Coburg Road near Port Elgin and Route 940 (Figure 9). The pit exposes interbedded hematite-rich siltstone, fine-grained calcareous sandstone and medium-grained sandstone (sample lithology) with coalified plant debris and mudstone intraclasts. Mud-chip conglomerate, containing abundant iron oxides and malachite staining, underlies the sandstone. ***Richibucto Formation.***

**Sample 95SJ AR-6** was obtained from a quarry on the west side of Route 16 across from the Mount Whatley interchange (Figure 10). Sandstone at this locality is light yellowish brown, fine-grained, and

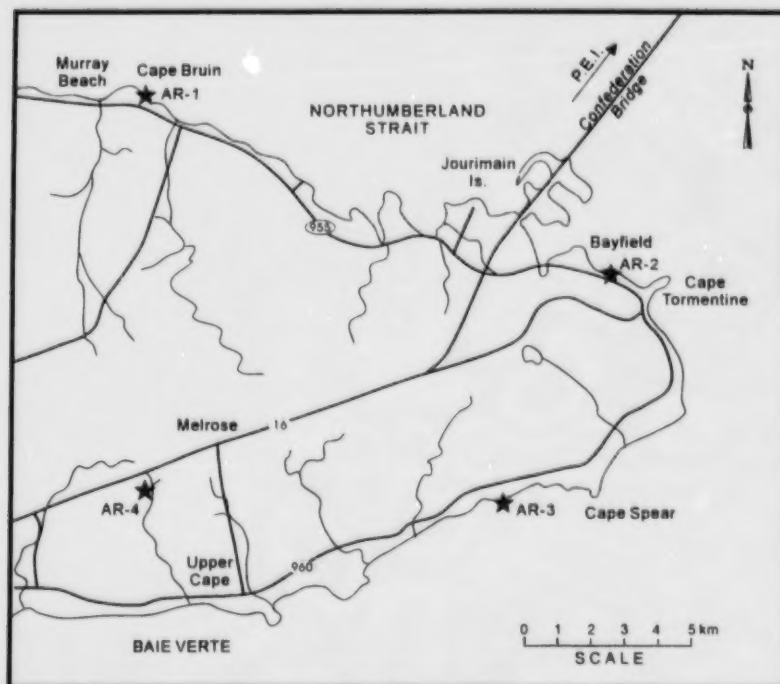


Figure 8. Location map for samples AR-1 to AR-4.

contains abundant coalified plant fragments. It is highly quartzose and had to be resampled in order to obtain enough muscovite. The yellow hue is due to the presence of limonite. The sandstone has interbeds of quartz-pebble conglomerate and olive green shale. **Boss Point Formation.**

**Sample 95SJ AR-10** was collected on a tributary of Calhoun Brook approximately 600 m west of a secondary road between the communities of Evangeline and Lakeville, near Moncton (Figure 11). Grey, medium-grained, highly micaceous sandstone containing abundant plant debris is exposed in the bottom and low bank of the stream. **Richibucto Formation.**

## RESULTS AND CONCLUSIONS

Release spectra diagrams for muscovite (Figure 12) show concordant data with plateau ages given for all but sample AR-6. The low apparent ages in the initial heating steps are generally attributed to a quantity of radiogenic argon lost at grain boundaries (Faure 1977). A small vacuum leak experienced during the analysis of AR-6 required that an estimate of the age be given using the two largest heating increments. As illustrated in Figure 13, the plateau ages appear to cluster into three discrete groups, around the Late Devonian–Carboniferous boundary, in the Late Devonian, and in the Middle Devonian. The absolute ages, including analytical errors, range from ca. 354 Ma (Tournaisian) to ca. 394 Ma (Emsian) using the revised Devonian time scale of Tucker *et al.* (1998).

The only Cumberland Group sample, AR-6 from the Boss Point Formation, gives an age that is virtually identical to samples AR-1 and AR-2 from the Richibucto and Tormentine formations.

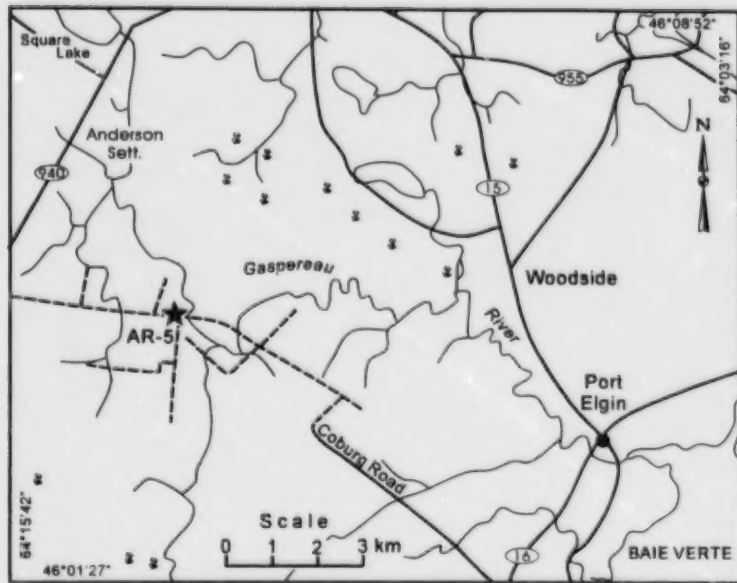


Figure 9. Location map for sample AR-5.

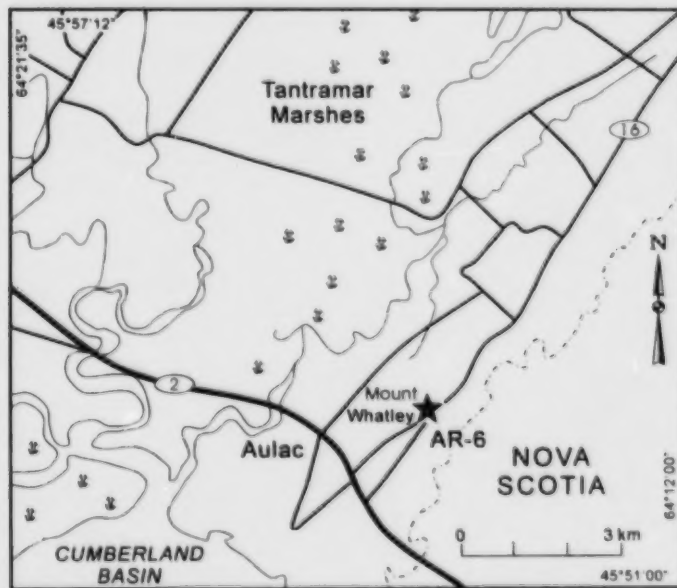


Figure 10. Location map for sample AR-6.

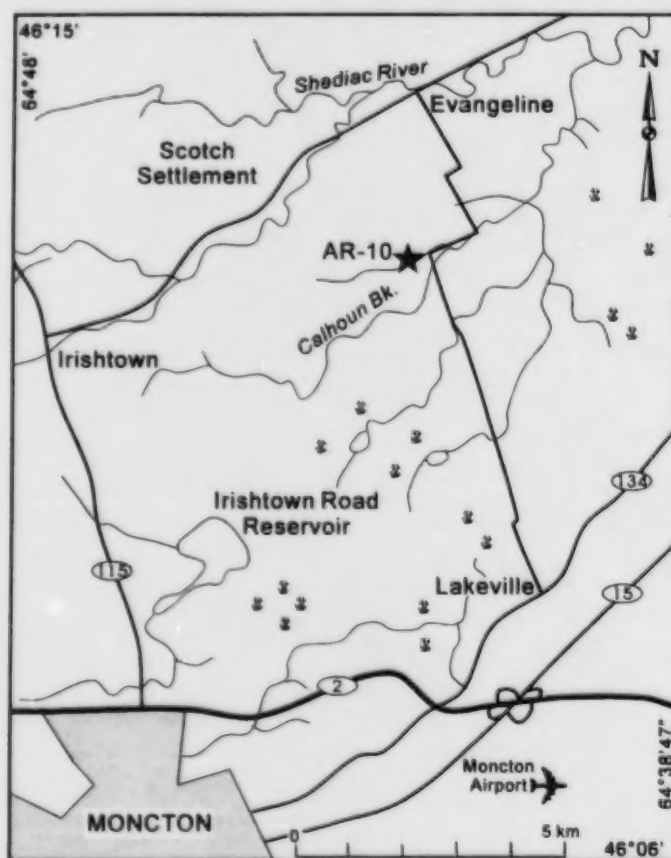


Figure 11. Location map for sample AR-10.

Detrital muscovite ages for the Richibucto Formation had the greatest variation, spanning the entire range from Middle Devonian to Early Carboniferous. The Richibucto Formation from Calhoun Brook (near Evangeline) north of Moncton (AR-10 on Figure 11) yielded the only, somewhat older (Middle Devonian), age of  $390.7 \pm 3.0$ . It is noteworthy that siltstone in the vicinity of Evangeline yielded spores that suggest a latest Stephanian age (Dolby 1996), anomalously young for this formation. If the young age is correct, it is tempting to speculate that the youngest deposits, such as those near Evangeline, were progressively sourcing deeper (older) levels of a pre-Carboniferous terrane. It is equally possible that the variation in muscovite ages exhibited by the Richibucto Formation may simply reflect the larger sample population.

The relative uniformity of the argon age data suggests that the detrital muscovite sampled from the Boss Point, Richibucto and Tormentine formations probably originated from the same source terrane(s). The most obvious local source for Devonian age muscovite is the central and southern plutonic belts (Whalen 1987) that flank the southwestern margin of the Maritimes Basin in New Brunswick (Figure 1). In the southern plutonic belt, McLeod (1991) reported an  $^{40}\text{Ar}/^{39}\text{Ar}$  muscovite age of  $384 \pm 7$  for the John Lee Brook Granite, the only muscovite-bearing phase within the Saint George Batholith. Including the large error, the age of the John Lee Brook Granite falls within the limits of sample AR-10 (Figure 13). Within the central plutonic belt, muscovite-bearing phases in the Pokiok Batholith give U-Pb ages of  $402 \pm 1$  Ma

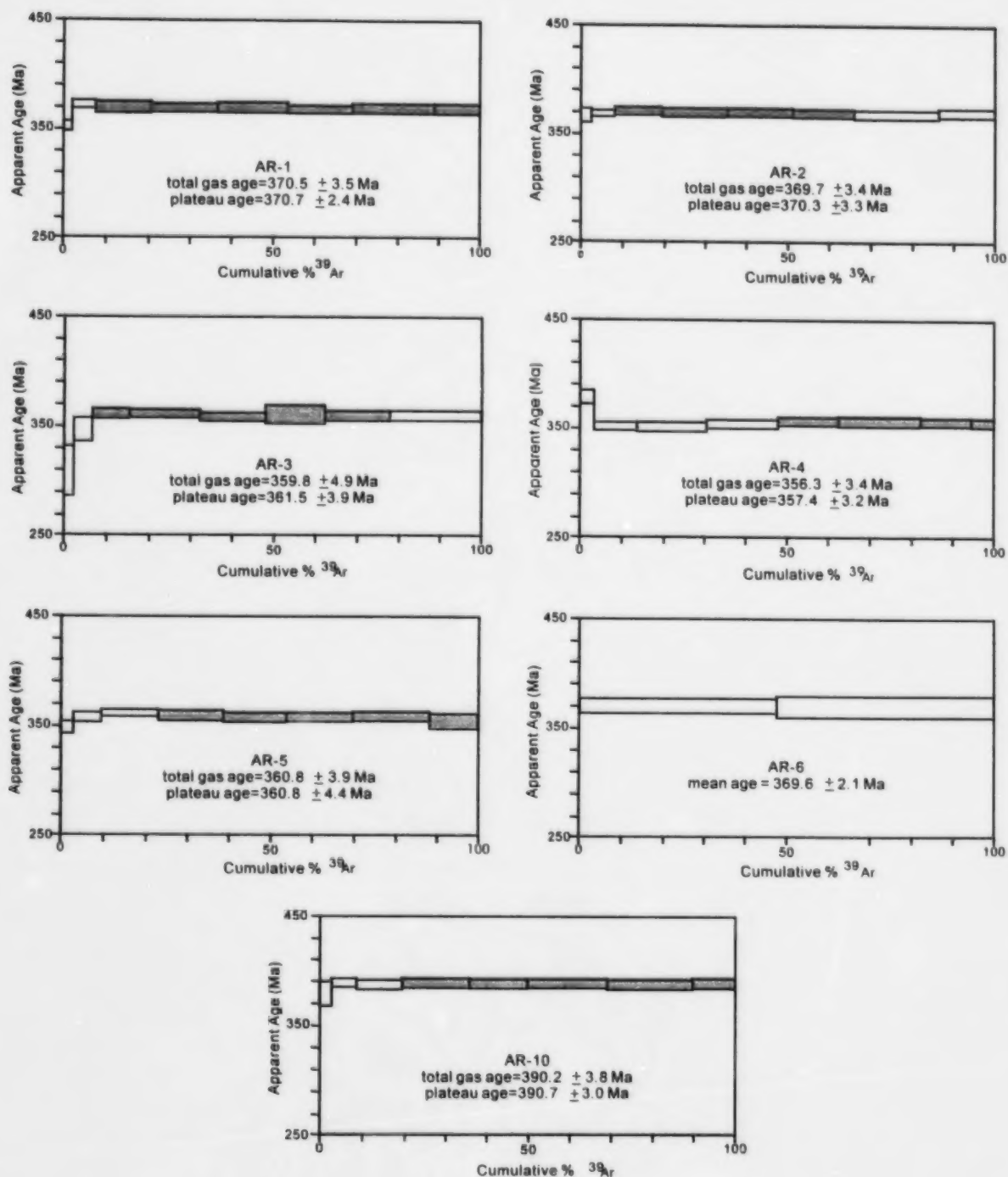


Figure 12. Release spectra diagrams for samples AR-2 and AR-3 (Tormentine Formation); AR-1, AR-4, AR-5 and AR-10 (Richibucto Formation); AR-6 (Boss Point Formation). Shaded bars indicate dates used to calculate the plateau age.

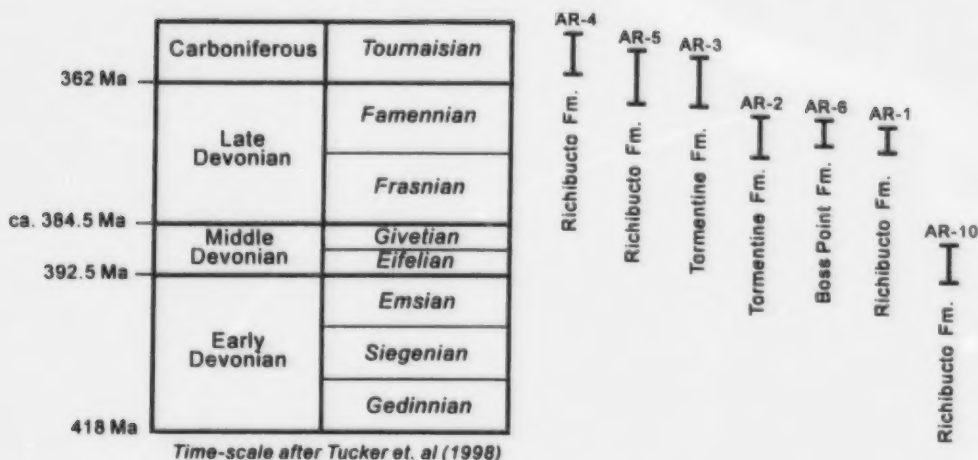


Figure 13. Chart showing the range in age of muscovites from Upper Carboniferous sandstones.

and  $409 \pm 2$  Ma (Bevier and Whalen 1990), too old to have been the source for any of the sandstones sampled during this study. The 380 Ma age reported for the Burnthill Granite suite (MacLellan *et al.* 1990; Whalen 1993) is also unlikely to be the source for the detrital muscovites dated in this study because it is outside of the error limits of every sample.

Highly micaceous wackes of the Flume Ridge Formation that fringe the Maritimes Basin to the southwest of the study area are another potential source of muscovite. However, an unpublished  $^{40}\text{Ar}/^{39}\text{Ar}$  age of  $452 \pm 4$  Ma for detrital muscovite from the Flume Ridge Formation (personal communication, M.J. McLeod, 1999) suggests this is not a feasible source. Muscovite from metasedimentary phyllite exposed within the Broad River Group in the Caledonia Highlands is very fine grained and with thermal ages of ca. 410 to 430 Ma (Dallmeyer and Nance 1994) is unlikely to have been the source of mica in the Carboniferous sandstones. With the exception of the John Lee Brook Granite, the local basement rocks do not appear to be the source for the detrital muscovites in the sandstones in this study.

Paleocurrent analyses compiled by Gibling *et al.* (1992) indicate a predominantly northeast paleoflow for Upper Carboniferous rocks over much of Atlantic Canada. Using a large number of paleoflow readings and a tectonic reconstruction, they suggest that Late Carboniferous and Early Permian drainage originated in the fold and thrust belt of the central and northern Appalachian mountains but that local uplands were additional important sediment source areas. "Neo-Acadian" age (366–350 Ma) plutonism and metamorphism in central Massachusetts and southwestern New Hampshire documented in Robinson *et al.* (1998) is consistent with the Famennian–Tournaisian age muscovites from samples AR-1 to AR-6. Derivation from a southwestern terrane such as this remains the most viable source for the muscovite in the Upper Carboniferous sandstones.

$^{40}\text{Ar}/^{39}\text{Ar}$  dating of detrital muscovites was not successful in delineating different sources for sediment in the Cumberland and Pictou groups. Compositional differences, such as the content of quartz and mica, are seen as a useful tool to distinguish between grossly similar lithostratigraphic units.

## ACKNOWLEDGEMENTS

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## THE EXTECH II GEOSCIENCE DATABASE VIEWER (CD-ROM), BATHURST MINING CAMP, NORTHERN NEW BRUNSWICK, CANADA (MINERAL RESOURCE REPORT 99-5) ‡

John P. Langton<sup>1</sup>, Peter G. Banks<sup>1</sup>, and Rob van de Poll<sup>2</sup>

<sup>1</sup>New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch,  
P.O. Box 50, Bathurst, New Brunswick, CANADA E2A 3Z1 (jlangton@gov.nb.ca; peterbanks@excite.com)

<sup>2</sup>Universal Systems Limited, 264 Rookwood Ave., Fredericton, New Brunswick, CANADA E3B 2M2  
(vdpoll@universal.ca)

LANGTON, J.P., BANKS, P.G., and VAN DE POLL, R. 1999. The EXTECH II Geoscience Database Viewer (CD-ROM), Bathurst Mining Camp, northern New Brunswick, Canada (Mineral Resource Report 99-5). *In* Current Research 1998. Edited by B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 99-4, 2 p.

The EXTECH II CD-ROM is a self-contained CARIS-based viewer that will display a wide variety of spatial data commonly used in mineral exploration. The data set covers nine 1:50 000 scale NTS map sheets (21 O/1, O/2, O/7, O/8, O/9, O/10 and 21 P/4, P/5, P/12), which encompass the Bathurst Mining Camp. This repository of data contains information gathered during the five-year (1994–1999) EXTECH (EXploration and TECHnology) Project, as well as data from Minerals and Energy Division archives and databases. The CD contains approximately 350 megabytes of information pertaining to: topography; bedrock geology; surficial geology; airborne geophysics; till, stream, and bedrock geochemistry; radiometrics; mineral deposits; claim blocks (1955–1997); diamond-drill holes; exploration trenches and pits; fossil and radiometric age-date localities.

Le CD-ROM EXTECH-II est un lecteur autonome pour CARIS qui peut afficher un vaste éventail de données spatiales couramment utilisées dans le domaine de l'exploration minière. L'ensemble de données couvre neuf feuilles topographiques du SNRC (21 O/1, O/2, O/7, O/8, O/9, O/10 et 21 P/4, P/5, P/12) à l'échelle de 1/50000 englobant le Camp minier de Bathurst. Cette banque de données renferme des renseignements amassés au cours de la réalisation du projet quinquennal (1994–1999) EXTECH (EXploration et TECHnologie) ainsi que des données des archives et des bases de données de la Division des ressources minières et de l'énergie. Le CD contient environ 350 Mo de données ayant trait à la topographie; à la géologie du substrat rocheux; à la géologie des formations superficielles; à la géophysique aérienne; à la géochimie du till, des cours d'eau et du substrat rocheux; à la radiométrie; aux gîtes minéraux; aux lots de claims (1955–1997); aux puits forés au diamant; aux tranchées et aux trous de prospection; aux fossiles et aux emplacements d'âge radiométrique.

A set of simple functions or "tools," designed specifically for this CD, can be used to extract general information, or to query the attributes of displayed items. A system of simple drop-down menus allow the user to selectively choose which data layers to display. The data are displayed in either vector or raster format. Vector data are displayed as maps, and consist of point data (symbols), lines, polygons (closed areas representing bedrock units, surficial units, or claim blocks), and text. Raster data are displayed as colour or gray-scale raster images, which commonly serve as backdrops for vector maps. All of the data on the CD were compiled from publicly available documents obtained from the Geological Survey of Canada and the Minerals and Energy Division of the New Brunswick Department of Natural Resources and Energy.

‡ Contribution to the EXTECH-II Program (New Brunswick Geological Surveys Branch ordinary budget).

Data compiled from Provincial assessment reports (claim-block, drill-hole, and trench data) were coded with their assessment-report (Mineral Exploration Report of Work) number. The user can query any of these items on-screen, determine the assessment-report number, and obtain a copy of the original file from Minerals and Energy Division archives in Bathurst or Fredericton for more detailed follow-up research. In addition, a "claim-block information" function has been developed for this CD. To employ this function, the user "draws" a polygon of any shape or size over an area of interest. The function will then return a list of assessment-report numbers for all reports pertaining to the claim-blocks that intersect the user-defined polygon.

The URN (unique record number) for each mineral deposit/occurrence is also listed on-screen. This number can be used to search the New Brunswick Mineral Occurrence Database for full information on any known occurrence. Querying any mineral occurrence/deposit on-screen will spawn a window containing a synopsis of the information contained in the New Brunswick Mineral Occurrence Database.

Earth scientists and mineral explorationists are well acquainted with the need to compile various data types, such as geological, metallogenic, geochemical, and geophysical data, claims maps, satellite images, etc., in their search for favourable exploration areas. More often than not, some of these data are available only in hard-copy format, and are typically not at the required scale. To accurately integrate these data, it is commonly necessary to enlarge or reduce paper copies and transfer the data to a common base-map using a light-table. The EXTECH II CD replaces this "light-table overlay" approach to data compilation with a computer-based system that operates at any scale, and is fast and flexible in the types of data that can be integrated, analyzed, and displayed. The various types of spatial data on the EXTECH II CD are displayed on individual map layers that are all referenced to the same real-world coordinates. This means that when querying any point location on the map, any distance between two points, accumulated distances, or any compass bearing, the results will be accurately displayed in real-world coordinates and orientations. A tutorial is included on the CD to acquaint you with the installation procedure, user interface, menu system, tools, and reference lists on the CD.

The CD is available from the New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division for \$50.00.

## **CREDITS AND ACKNOWLEDGEMENTS**

We gratefully and proudly acknowledge that this data product is the combined work of many members of the EXTECH II Program. Additional assistance in the form of digital data support was provided by P. Rennick of the New Brunswick Department of Natural Resources and Energy and D. Wright of the Geological Survey of Canada. Technical support and assistance was provided by Universal Systems Limited (Head Office, Fredericton, N.B.) for the development of the EXTECH Data Viewer.

# REPORT OF *GYRACANTHUS* (CHORDATA: ACANTHODII) AND OTHER UPPER CARBONIFEROUS FISH FROM THE MINTO FORMATION, NEW BRUNSWICK (NTS 21 I/4) ‡‡

Randall F. Miller

Steinhammer Palaeontology Laboratory, New Brunswick Museum,  
277 Douglas Avenue, Saint John, New Brunswick, CANADA E2K 1E5 (e-mail: millerrf@nb.aibn.com)

MILLER, R.F. 1999. Report of *Gyracanthus* (Chordata: Acanthodii) and other Upper Carboniferous fish from the Minto Formation, New Brunswick (NTS 21 I/4). In *Current Research 1998*. Edited by B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 99-4, pp. 37-43.

Discoveries of fossil fish from the coalfields of Nova Scotia have established most of what we know about this group of vertebrates from the Upper Carboniferous of eastern Canada. Collections date back to the middle 1800s, with many of the original descriptions found in publications by J.W. Dawson. Upper Carboniferous deposits in New Brunswick have not yielded a similar fauna. This note provides a preliminary report of *Gyracanthus* and other fish remains recently recovered from the Minto Formation south of Chipman. This collection indicates that the Upper Carboniferous basins of New Brunswick were populated by a fish fauna similar to that described from Nova Scotia.

La majeure partie de ce que nous savons au sujet de ce groupe de vertébrés du Carbonifère supérieur de l'Est du Canada repose sur des découvertes de poissons fossiles des terrains houillers de la Nouvelle-Écosse. Les collections remontent au milieu des années 1800; un grand nombre des descriptions originales se trouvent dans des publications de J.W. Dawson. Les gîtes du Carbonifère supérieur du Nouveau-Brunswick n'ont pas mis au jour de faune similaire. Cette note fournit un rapport préliminaire sur le *Gyracanthus* et d'autres restes de poissons récemment recouverts dans la Formation de Minto, au sud de Chipman. Cette collection révèle que les bassins du Carbonifère supérieur du Nouveau-Brunswick étaient peuplés par une faune aquatique semblable à celle décrite dans le cas de la Nouvelle-Écosse.

## INTRODUCTION

Reports of vertebrate remains in Upper Carboniferous rocks in New Brunswick are rare (Miller 1996) even though numerous palaeontological reports concerning the Upper Carboniferous of New Brunswick have been published since the last century (Bailey and Matthew 1873; Stopes 1914; Dyer 1926; Muller 1951; Bell 1962). In part, the lack of vertebrate fossils may be a result of most research having been directed toward stratigraphy and paleobotany. Bell (1962) described plant fossils from the Minto coalfields in relative detail based on collections made as early as 1926 (Dyer 1926; Muller 1951), but surprisingly reported no vertebrate remains.

‡‡ New Brunswick Museum ordinary budget.

The fossils noted here probably represent the only recorded occurrence in New Brunswick of most of these animals from the Upper Carboniferous. An undescribed fossil of meglichthynid fish was recovered from the Clifton Formation northeast of Bathurst in 1997, where Bell (1962) had also described plant fossils. The fish assemblage from the Minto Formation comprises acanthodians, chondrichthyes, dipnoans, sarcopterygians and palaeoniscoids and is represented by isolated teeth, scales and spines. Among the specimens are three fossils of *Gyracanthus*, a large acanthodian spine relatively rare in North America. Similar fossil assemblages have been recorded from Nova Scotia since the mid-1800s (Calder 1998).

The fish fauna described here was recovered from bivalve-bearing organic-rich limestones, similar to beds described from Joggins. The Upper Carboniferous fish assemblages from Joggins and elsewhere in Nova Scotia are often interpreted as representing restricted freshwater habitat, but other interpretations exist that suggest estuarine salinities (Calder 1998).

## LOCATION AND STRATIGRAPHY

The fossils were collected by Michael Lee from coal extraction pits along Coal Creek south of Chipman (approximately 46°07'00" N; 65°50'00" W) (Figure 1). The fossils were found in bivalve-bearing organic-rich limestones, probably within the Minto Formation. Macrofossils and miospores indicate a Westphalian C age for the upper part of the Minto Formation (Williams *et al.* 1985). Recent mapping of the Chipman map sheet places the Minto Formation within the Cumberland Group (St. Peter 1997). Muller (1951) and Bell (1962) had previously assigned the Minto Formation to the Pictou Group. The Minto Formation is described as including fossiliferous sandstone, conglomerate, fossiliferous siltstone, shale and coal. Although no mention was made of a bivalve-bearing limestone by St. Peter (1997), the unit may be thin and only occasionally exposed. Vertebrate remains are well-known in similar Cumberland Group lithotypes in Nova Scotia. Further work will be needed to confirm the extent and stratigraphic position of this unit.

## GENERAL DESCRIPTION OF FOSSILS

Fish fossils occur as isolated teeth, scales and spines. They include disarticulated remains of acanthodians (Figure 2), chondrichthyes (Figure 3), dipnoans, sarcopterygians (Figure 4) and palaeoniscoids, scattered in a black shelly limestone. None of the sediments has been prepared for microfossil analysis. The sites are still under active investigation. Valves of the pelecypod *Naiadites*, as well as gastropods and *Spirorbis* tubes can also be seen. All identifications are preliminary. Taxa have been arranged in the same manner as presented by Calder (1998), although many variations on classification exist (Long 1995).

### Phylum Chordata

#### Class Acanthodii (spiny sharks)

*Gyracanthus* cf. *G. duplicatus* Dawson

#### Class Chondrichthyes (cartilaginous fishes)

##### Order Xenacanthida

*Orthacanthus* sp.

genera indeterminate

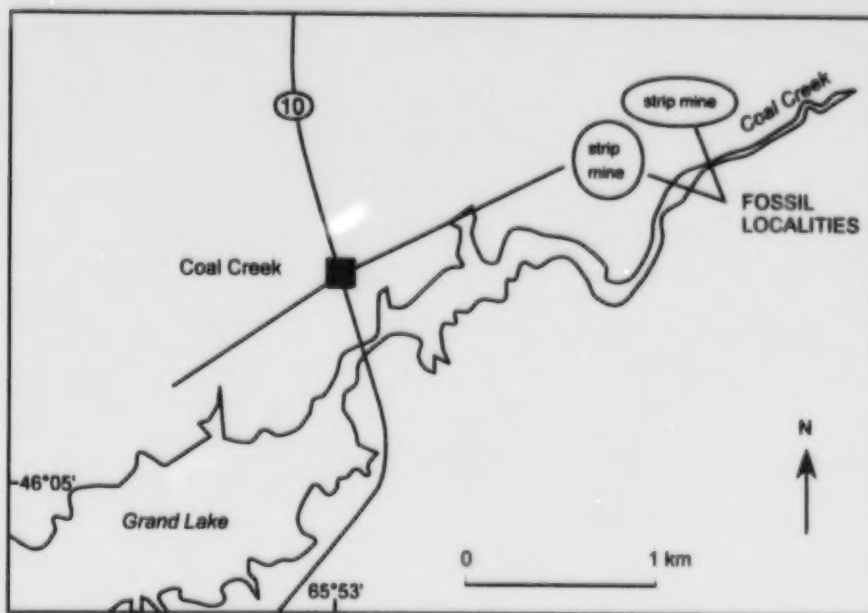


Figure 1. Location of fossil sites along Coal Creek, south of Chipman, New Brunswick.

- Class Osteichthyes (bony fishes)
  - Subclass Actinopterygii (ray-finned fishes)
    - Order Palaeonisciformes
      - genera indeterminate
  - Subclass Sarcopterygii (lobe fins)
    - Order Crossopterygii
      - cf. *Megalichthys*
      - cf. *Rhizodopsis* or *Rhizodus* sp.
  - Superfamily Dipnoi (lungfish)
    - genera indeterminate

## DISCUSSION

Among the fossils recovered, one of the most interesting is *Gyracanthus*, (Figure 2), an acanthodian fin spine relatively common in Europe, but rare in North America (Baird 1978; Calder 1998). *Gyracanthus* is a form genus based on fin spines ornamented with parallel ridges on both sides from the anterior margin obliquely, posteriorly and proximally (Denison 1979). According to Denison (1979) spines referred to *Gyracanthus* range in age from Lower Devonian to Upper Carboniferous and probably belong to a number of genera. The largest and most complete of three specimens collected by Michael Lee is a minimum 152 mm long, consistent with the size range for *G. duplicatus* illustrated by Baird (1978). *Gyracanthus duplicatus* was described by Dawson in 1868 from the Upper Carboniferous at Joggins and specimens have been found at Parrsboro, Grand Etang and Inverness (Baird 1978). Dawson (1868) described a much larger specimen, *G. magnificus*, from the Mabou Group on Cape Breton Island. Baird



Figure 2. *Gyracanthus* cf. *G. duplicatus* Dawson from the Minto Formation, New Brunswick. Scale bar = 8 cm.



Figure 3. Specimen of *Orthacanthus* from the Minto Formation, New Brunswick. Scale bar = 1 cm.



Figure 4. Rhizodont tooth from the Minto Formation, New Brunswick. Scale bar = 1 cm.

(1978) described the Nova Scotia finds as the total record of Upper Carboniferous *Gyracanthus* in the Western Hemisphere. Later, in an addendum to the paper, he reported an additional suite of specimens from Illinois. The specimens noted here add a significant number to the known specimens from the Maritimes.

Xenacanth remains are well known from Carboniferous and Permian deposits in Europe and have been well documented in places like the Saar-Nahe Basin in Germany (Hampe 1994). In North America, xenacanths have not been as well studied, although since a publication by Hotton (1952) a number of good descriptions have appeared for specimens from the mid-west United States (Zidek 1993). In Canada, Masson and Rust (1984) described *Orthacanthus* teeth in the Upper Carboniferous Morien Group, along with lungfish and acanthodian remains. At least some of the shark teeth noted here probably belong to the genus *Orthacanthus* (Figure 3).

Calder (1998) reported that *Sagenodus* lungfish scales are relatively common in bivalve-bearing organic-rich limestones in Nova Scotia and they are a common component of the Upper Carboniferous fish fauna. A small number of lungfish remains have been noted in the samples described here, but they have not been identified.

Crossopterygian teeth and scales, probably *Rhizodopsis* or *Rhizodus* (Figure 4) are relatively common in the samples from New Brunswick. Rhizodonts reached their peak of diversity and size in the Carboniferous. The largest *Rhizodus* may have reached 6–7 m in length (Long 1995). A few large scales resembling *Megalichthys* have also been recovered. Megalichthyinids were a highly successful group of advanced osteolepidids that survived until the Middle Permian. They reached sizes of about 1 m and inhabited the coal swamps and lakes around Gondwana and Euramerica (Long 1995).

The paleoenvironment indicated by the fish assemblage hinges on a question of whether the organisms indicate marine or freshwater conditions. At other localities, various interpretations have been applied to species found in the assemblage described here. Generally, they are considered to have inhabited non-marine conditions. The clam *Naiadites* is described as a freshwater clam, probably able to tolerate brackish water (McKerrow 1978). Xenacanthid sharks are among the few elasmobranch fishes thought to have lived almost exclusively in non-marine environments (Zangrel 1981) and were predominantly inhabitants of freshwater lakes and streams. Some species are thought to have been specially adapted to shallow, vegetation-choked, coal swamps (Dick 1981). Consequently, Masson and Rust (1984) described Upper Carboniferous *Orthacanthus* and other fish remains from Nova Scotia, and used their presence to confirm the nonmarine nature of the sediments.

The assemblage described here was recovered from bivalve-bearing organic-rich limestones, similar to beds described from the section at Joggins. The Upper Carboniferous fish assemblages from Joggins and elsewhere in Nova Scotia are often interpreted as representing restricted freshwater habitat, but Calder (1998) reported that fossils, including a xenacanth tooth recovered from bivalve-bearing organic-rich limestones in the Cumberland Group, have strontium isotope signatures consistent with estuarine salinities. The marine–freshwater debate will not be settled here, but the assemblage indicates the possibility of estuarine conditions within part of the Minto Formation.

## ACKNOWLEDGEMENTS

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## FOLLOW-UP TILL GEOCHEMISTRY IN THE MILLVILLE (NTS 21 J/3) MAP AREA, YORK COUNTY, NEW BRUNSWICK †

Allen A. Seaman

New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch,  
P.O. Box 6000, Fredericton, New Brunswick, CANADA E3B 5H1 (e-mail: aaseaman@gov.nb.ca)

SEAMAN, A.A. 1999. Follow-up till geochemistry in the Millville (NTS 21 J/3) map area, York County, New Brunswick. *In* Current Research 1998. Edited by B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 99-4, pp. 45-55.

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Follow-up till samples were collected from 34 sites proximal to ten anomalous sites identified by the original till sampling project in the Millville (NTS 21 J/3) map area. These follow-up samples were analysed for the same suite of elements as the original samples, using the same analytical methods. In addition, duplicate splits of the original anomalous samples were analysed. The results for the duplicate splits confirmed the original anomalous values. However, few of the follow-up samples returned anomalous or threshold values. It is suggested that the lack of elevated values in the follow-up samples may result from the comparative thickness of the till and the extensive glacial dispersal in the area. Where the tills are thick, samples collected within hand reach of the surface are being obtained from material that has a significant distal component and, hence, are representative of the regional bedrock geochemistry. Alternatively, where the till is thin, as at some of the anomalous sites, samples are collected from close to the bedrock contact and tend to contain less distal material; hence, they are more representative of the mineralization that the local bedrock may contain.

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Des échantillons de till de suivi ont été prélevés de 34 points à proximité de dix emplacements anomaux repérés grâce au projet initial d'échantillonnage de till réalisé dans le secteur cartographique de Millville (SNRC 21 J/3). Les chercheurs ont analysé la teneur de ces échantillons en composants de la série d'éléments vérifiés dans les échantillons initiaux au moyen des mêmes méthodes analytiques. Ils ont en plus analysé des doubles obtenus par fractionnement des échantillons anomaux initiaux. Les résultats des analyses des fractions doubles ont confirmé les valeurs anormales initiales. Peu d'échantillons de suivi ont toutefois affiché des valeurs anormales ou limites. On pense que l'absence de valeurs élevées dans les échantillons de suivi pourrait être due à l'épaisseur comparative du till et à la dispersion glaciaire étendue dans ce secteur. Lorsque les tills sont épais, les échantillons prélevés à une portée pratique de la surface proviennent d'un matériau dont une part substantielle des composants sont éloignés; ils sont donc représentatifs de la structure géochimique régionale. Par contre, lorsque le till est mince, comme dans certains des emplacements anomaux concernés, on prélève les échantillons à proximité de la zone de contact avec le substrat rocheux et ils ont tendance à renfermer moins de matières distales; ils sont donc plus représentatifs de la minéralisation que pourrait abriter le substrat rocheux local.

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† New Brunswick Geological Surveys Branch ordinary budget.

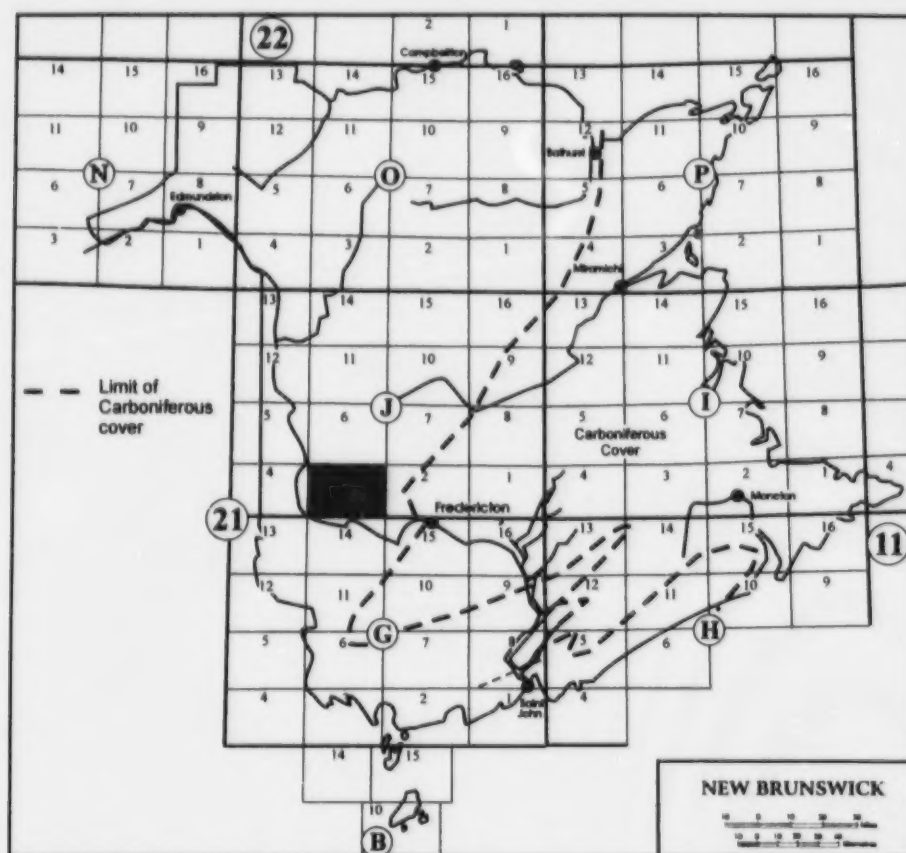


Figure 1. Location of the Millville (NTS 21 J/3) map area.

## INTRODUCTION

From 1995 to 1997, till sampling was conducted in the Millville (NTS 21 J/3) map area (Figure 1) using the standard 2 km sampling grid adopted for other till geochemistry investigations in southwestern New Brunswick (Seaman 1997, 1998). The threshold levels calculated for Millville East (Seaman 1997) were, with the exception of Cu, 1.5 to 2.5 times higher than the equivalent threshold levels calculated for Millville West (Seaman 1998) (see Table 1). [Threshold levels were defined as two standard deviations above the mean, calculated on the population of basal till samples, and with extreme high values deleted. Anomalies were defined as four standard deviations above this mean]. The threshold levels for Millville West are generally comparable to those for the entire southern Pokiok Batholith project area (21 G/NW) (Table 1). Therefore, the background metal values are considerably higher in the Millville East area than they are in adjacent areas to the south and west. However, despite these higher threshold levels, a number of till anomalies were identified in Millville East (Seaman 1997). In contrast, only two till anomalies of significance were identified in the Millville West area (Seaman 1998): a Pb anomaly in the north-central part of the map area (close to a Pb-Zn anomaly in Millville East), and an As-Sb dispersal train that appears to be derived from a source to the north of the map area (to be dealt with in a future report).

**Table 1. Threshold Levels (Mean Plus Two Standard Deviations)  
in the East and West Halves of the Millville Map Area,  
and in the Southern Pokiok Batholith Area (21 G/NW)**

Element	MV	MV-E	MV-W	SPB
As	38	51	26	30
Au	7 ppb	9 ppb	6 ppb	7 ppb
Cu	51	53	48	40
Mo	2	3	2	2
Pb	39	49	23	34
Sb	2.8	3.2	1.8	2.7
Sn	4	5	2	2
W	4	4	2	4
Zn	113	151	86	82

Note: Units are in parts per million (ppm) unless otherwise indicated as parts per billion (ppb).

MV Millville (NTS 21 J/3) [MV-E and MV-W data combined]

MV-E Millville East (NTS 21 J/3E)

MV-W Millville West (NTS 21 J/3W)

SPB Southern Pokiok Batholith area (NTS 21 G/11, G/12, G/13, G/14)

During the summer of 1998, follow-up samples were collected from 34 sites around six of the anomalous areas (ten anomalous sites) in the north-central and eastern parts of the map area. The purpose of this follow-up sampling was to confirm the geochemical anomalies at the original sample sites and to assess the size of the anomalous areas. The follow-up work involved sampling at reasonably accessible sites in the vicinity of the original anomalous sites. Thirteen sites were sampled around the Pb and Pb–Zn anomalies in the Otter Brook–Bear Lakes–Northeast Lakes area (north-central part of the map area); twelve sites were sampled around the Au, As, Cu and Sb anomalies in the Staples Settlement–Wiggins Mills area (southeastern part of the map area); three sites were sampled around the Cu–Mo anomaly in the northeastern corner of the map area (Grand John Lake area); and two sites each were sampled in the vicinity of the multi-element anomalies at Howland Ridge, Pughs Peak and Lower Hainesville. The locations of the follow-up sites in relation to the original sites and the regional bedrock geology are illustrated in Figure 2. [The lithologic characteristics of the bedrock units are summarised in Table 2, based on the descriptions of Lutes (1987) and Venugopal (1979, 1981, 1982)]. Sampling procedures and analytical methodology were the same as used in the original surveys (see Seaman 1997, 1998). The full range of geochemical and geological data for both the original and the follow-up sites is presented by Seaman (1999). In the discussions that follow, threshold and anomalous values are calculated as noted above, but based on the entire population of basal till samples from the Millville map area (including the follow-up samples).

## THE OTTER BROOK–BEAR LAKES–NORTHEAST LAKES AREA

The basal till sample from site MV-L01a, just to the north of Otter Brook, returned a highly anomalous Pb value (154 ppm and 160 ppm, on two splits of the same sample) (Seaman 1998), while that from site MV-N03a, just to the west of Upper Northeast Lake, returned highly anomalous Pb and Zn values (221 ppm and 319 ppm, respectively) (Seaman 1997). An ablation till sample from site MV-P04, to the south of Lower Northeast Lake, also exhibited anomalous Pb (121 ppm) (Seaman 1997). In addition, Ruitenberg

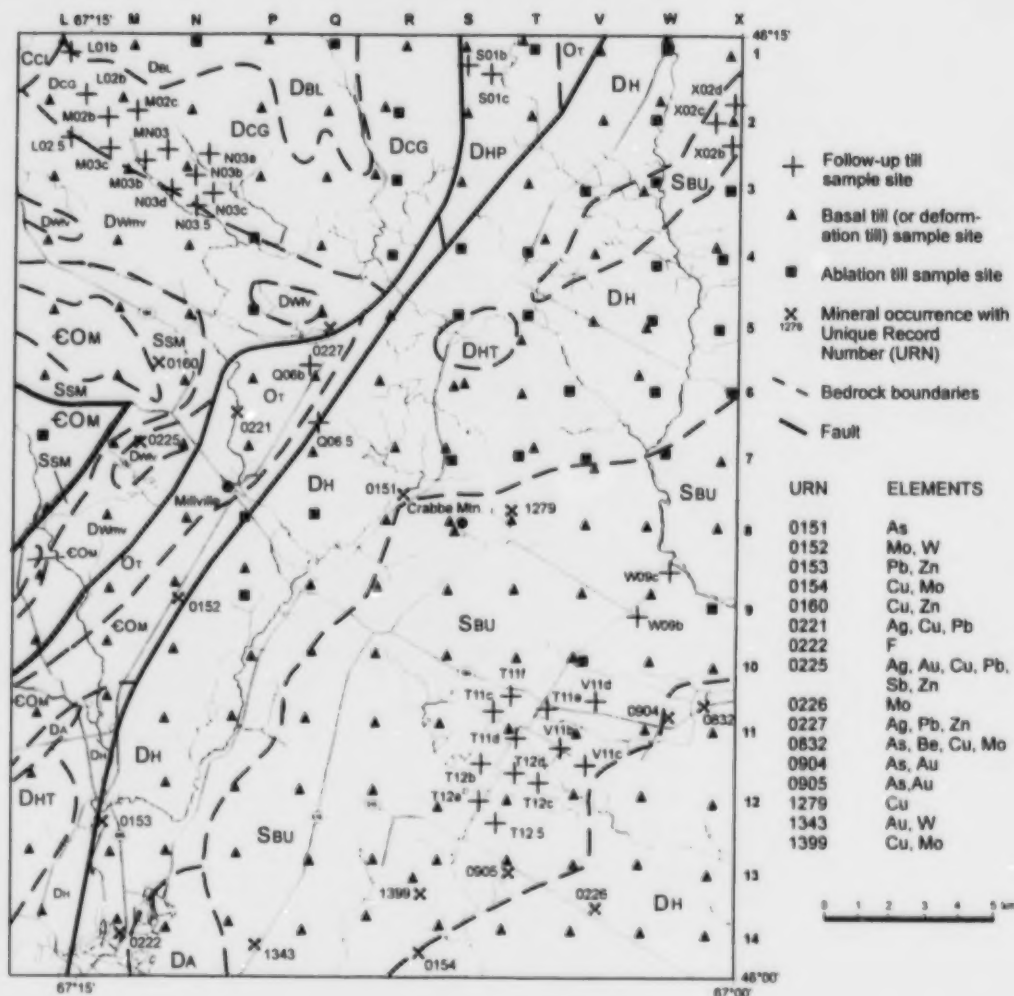


Figure 2. Location of follow-up till sample sites with respect to the original sample sites and the regional bedrock geology [from Fyffe 1982, with updated unit designations (see Table 2)]

(1994) reported a soil-base-metal anomaly from the Upper Bear Lake area, across the ridge to the west of site MV-N03a, and Lamothe (1990) reported a Pb-Zn-Sn anomaly from a till site (85LFA0201) approximately midway between sites MV-L01a and MV-N03a. Seaman (1998) suggested that these anomalies might relate either to mineralization in rocks of the Costigan Mountain Formation or to a dispersal train extending from an unknown source to the north.

Thirteen follow-up sites (MV-L01b, -L02b, -L02.5, -M02b, -M02c, -M03b, -M03c, -MN03, -N03b, -N03c, -N03d, -N03e and -N03.5) were sampled from the area around these anomalous sites. All of these sites were in basal till, except for MV-M03b, which was in ablation till.

Re-analysis of the original samples from sites MV-N03a and MV-P04 confirmed the anomalies at these sites (194 ppm Pb and 275 ppm Zn for the former site; and 116 ppm Pb for the latter). Significantly, none

Table 2. Table of Bedrock Formations

System	Group	Formation	Map Unit	Lithology
Carbon-iferous		Carlisle	CCl	Red conglomerate and sandstone; minor mudstone and nodular limestone
Devonian	Pokiok Batholith	Allandale Granite	DA	Pink, muscovite-biotite granite
		Hawkshaw Granite	DH	Pink to light grey, biotite granite; minor hornblende-biotite granite and granodiorite
		Hartfield Tonalite	DHT	Light grey, biotite and hornblende-biotite granodiorite and tonalite
		Howard Peak Granodiorite	DHP	Grey hornblende-biotite tonalite and granodiorite containing xenoliths of schist and injected by granite veins
		Becaguimec Lake Gabbro	DBL	Greyish green gabbro
	Tobique	Wapske	DWmv	Greyish green mafic volcanic rocks; interbedded with light green to grey sandstone, siltstone, slate, and conglomerate
			DWlv	Pink to grey tuffs, grey to pink rhyolite, and pink quartz-feldspar porphyry; interbedded with light green to grey conglomerate, sandstone, siltstone, and slate
		Costigan Mountain	DCG	Pink to light grey rhyolite and felsic tuff; interbedded with grey sandstone, siltstone and slate
Silurian	Kingsclear	Burtts Corner	SBU	Grey, locally calcareous, micaceous wacke; interbedded with grey slate
	Perham	Smyrna Mills	SSM	Grey to light green calcareous sandstone, siltstone, and slate; with red to maroon ferromanganiferous siltstone and slate, and minor blue-grey limestone
Ordovician	Tetagouche		OT	Grey to pink rhyolite, tuff, and breccia; interbedded with green and maroon ferromanganiferous or black slate, grey chert and slate, and minor greyish green mafic volcanic rocks
Cambrian-Ordovician	Miramichi		COM	Olive green to grey wacke; interbedded with grey, green, and maroon slate and siltstone; quartz veins are common

of the follow-up samples returned elevated Pb or Zn values, including those from sites in close proximity to Lamothe's site and the Upper Bear Lake occurrence. Similarly, several samples collected from the southern part of the Coldstream map area, immediately to the north, returned sub-threshold values for Pb and Zn. However, a threshold value for Co (24 ppm) was obtained for the sample from site MV-L02.5 and a threshold value for As (39.7 ppm) was obtained for site MV-N03d.

These results suggest that the original anomalies are not part of a dispersal train. Rather, they probably represent occurrences of mineralization in rocks of the Costigan Mountain Formation that underlie the area, perhaps similar to the disseminated sulphide minerals reported by Ruitenberg (1994) from the Bear Lake prospect.

## THE STAPLES SETTLEMENT-WIGGINS MILLS AREA

The deformation till sample from site MV-T11a returned highly anomalous values for As (130 ppm) and Sb (17 ppm) and a threshold value for Mo (2 ppm, by ICP), while the basal till sample from nearby site MV-T11b was anomalous in Sb (7.0 ppm) and contained threshold levels of As (56 ppm), Co (28 ppm) and Ni (91 ppm). The basal till sample from site MV-T12a returned anomalous values for As (100 ppm), Au (12 ppb), Co (43 ppm), Cu (81 ppm) and Ni (149 ppm), and threshold values for Sb (3.2 ppm) and Zn (146 ppm). The basal till sample from site MV-V11a registered an anomalous value for Au (11 ppb) and a threshold value for Sn (4 ppm). Re-analysis of the samples from sites MV-T11b and MV-T12a confirmed the original analyses (58.1 ppm As, 29 ppm Co, 81 ppm Ni and 7.6 ppm Sb for the former; and 101 ppm As, 6 ppb Au, 42 ppm Co, 81 ppm Cu, 142 ppm Ni, 3.1 ppm Sb and 141 ppm Zn for the latter).

Four basal till sites were sampled around sites MV-T11a and MV-T11b, five were sampled around site MV-T12a, and three were sampled around site MV-V11a. The only anomalous value obtained from these follow-up samples was for As (79 ppm) at site MV-T12b. A threshold value for W was detected for site MV-T12e (4 ppm), and the first duplicate for site MV-T11f returned a threshold value for Au (10 ppb) while the second duplicate returned a threshold value for Mo (2 ppm).

Sites MV-T11b and MV-T12b directly overlie bedrock, while site MV-T12a lies in close proximity to several bedrock outcrops. The pebble samples collected from these sites appear to contain a greater proportion of locally derived clasts than do most of the follow-up sites. In particular, most of the clasts in the samples from sites MV-T12e, -T12.5, -V11b, -V11c and -V11d resemble those observed in the samples from the Otter Brook-Bear Lakes-Northeast Lakes area, and indicate a distance of glacial transport in the order of 20 km. These characteristics suggest that the geochemical anomalies may relate to bedrock sources in the Silurian Burtts Corner Formation of the immediate area, that are not represented in the geochemistry of the regional till sheet at the normal depth of sampling (approximately 0.4 to 0.7 m below the base of any organic litter overlying the mineral soil).

## THE GRAND JOHN LAKE AREA

The basal till sample from site MV-X02a, in the northeast corner of the Millville map area and about 1 km to the west of Grand John Lake [in the adjacent Burtts Corner (NTS 21 J/2) map area], returned anomalous values for Cu (146 ppm) and Mo (5 ppm, by ICP), and threshold values for As (42 ppm) and Pb (43 ppm). Re-analysis of the sample confirmed the Cu and Mo anomalies (140 ppm and 4 ppm, respectively), and the threshold As (49.9 ppm). The Pb value for this second split dropped below the threshold level (to 33 ppm), but the Co value (28 ppm) was above threshold level.

Basal till samples were collected from three sites around site MV-X02a. Site MV-X02b lies about 650 m to the south, site MV-X02c lies about 500 m to the west and site MV-X02d lies about 500 m to the north. No elevated values for Cu were detected in these follow-up samples. However, the sample from site MV-X02c returned an extremely anomalous value for Mo (12 ppm, by ICP), and Sb at the threshold level (2.8 ppm). Mo was at the threshold level (2 ppm) for the sample from site MV-X02b.

The lithological composition of the pebble sample collected from site MV-X02c was very different from that for the other two follow-up sites ('b' and 'd') [see Seaman (1999) for the general lithologic composition of the samples]. The pebble samples from the 'b' and 'd' sites comprise a mix of sedimentary, granitic

and volcanic rock clasts. The sedimentary rock fraction comprises a mix of generally angular wacke, hornfels, slate and metasediments of predominantly local provenance, and generally more rounded sandstone and siltstone of distal provenance. The 'd' sample also contained pebbles of reddish-coloured till, similar to the till observed at the surface at sites MV-X01 and MV-W02b to the north and west, respectively. This data suggests that the fine fraction of the till at these two sites contains a significant proportion of distal material. In contrast, the pebble sample from the 'c' site is dominated by very angular to angular black hornfels and slate clasts containing grey quartzose blebs or streaks. These pebbles are probably derived from the Ordovician Hayden Lake Formation, rather than from the Silurian Burtts Corner Formation (L.R. Fyffe, personal communication, 1999). The angularity of these clasts suggests that they are of local derivation. Caron (1996) has mapped a fault-bounded strip of similar Ordovician pelitic rocks at Crabbe Mountain, to the southwest. A strip of similar rocks, buried by glacial drift, could occupy a similar position in this area, i.e., between the Pokiok Batholith to the northwest and the Silurian Burtts Corner Formation to the southeast. The Cu and Mo anomalies in the till at sites MV-X02a and MV-X02c could be derived locally from fault-associated mineralization.

## HOWLAND RIDGE

The basal till sample from site MV-Q06a, at the north end of Howland Ridge Hill, exhibited anomalous As (170 ppm), Cu (148 ppm), Mn (3405 ppm), Pb (87 ppm), Sb (9.4 ppm) and Zn (870 ppm). These anomalous values were confirmed by the analysis of a second split of the sample (158 ppm As; 146 ppm Cu; 3091 ppm Mn; 83 ppm Pb; 9.7 ppm Sb; and 761 ppm Zn), which also returned threshold values for Au (10 ppb) and W (4 ppm).

Basal till samples were collected from two follow-up sites. Site MV-Q06b, approximately 300 m to the north-northwest of the original site, was anomalous in Mn (2279 ppm) and Sb (5.8 ppm), and contained threshold values for Cu (63 ppm) and Fe (6.29%). Site MV-Q06.5, approximately 1.4 km to the south of the original site, returned a threshold value for Sb (3.9 ppm). These results suggest that the mineralization in the Ordovician volcanic and sedimentary rocks of the Tetagouche Group in the immediate area, as reported by Connor (1993), is the source for the multi-element anomaly at site MV-Q06a.

## PUGHS PEAK

The basal till sample from site MV-S01a, on the lower northeast slope of Pughs Peak, returned anomalous values for Co (83 ppm), Cu (83 ppm), Mo (5 ppm, by ICP) and Zn (172 ppm), and threshold values for Fe (6.63 %), Ni (91 ppm) and Sn (5 ppm). A highly anomalous value for W (18 ppm) and a threshold value for Mo (2 ppm, by ICP) were obtained for the basal till sample from site MV-S02, 2 km to the south. Re-analysis of the samples from these two sites essentially confirmed the anomalies (34 ppm Co, 72 ppm Cu, 6.99 % Fe, 3 ppm Mo, 83 ppm Ni and 153 ppm Zn for MV-S01a, and 16 ppm W for MV-S02). However, threshold values for Sn for the former site and for Mo for the latter were not received on re-analysis.

Follow-up samples were collected from two basal till sites. Site MV-S01b is about 600 m to the south of site MV-S01a, on the southeast slope of Pughs Peak, and site MV-S01c is about 1 km to the southeast of site MV-S01a, in the low area adjacent to Howard Brook. The only elevated value returned from these follow-up samples was a threshold value for W (4 ppm) for site MV-S01c. This may indicate an area of W mineralization related to the fault contact between the Howard Peak Granodiorite and the Costigan Mountain Formation (Figure 2). The lack of other elevated values in the follow-up samples suggests that

the anomaly at site MV-S01a may be related to a bedrock source to the north. This will be addressed by future sampling of the Coldstream (NTS 21 J/6) map area.

## THE LOWER HAINESVILLE AREA

The basal till sample from site MV-W09a, along the road between Lower Hainesville and the Keswick River at Hayne, returned anomalous values for Co (34 ppm) and Ni (120 ppm), and threshold values for As (53 ppm), Cu (68 ppm), Fe (6.27 %), Pb (54 ppm), Sb (3.7 ppm) and Zn (113 ppm). Re-analysis of the sample essentially confirmed the original results, with anomalous values for As (58.8 ppm), Co (37 ppm), Ni (104 ppm) and Sb (4.6 ppm), and threshold values for Au (7 ppb), Cu (67 ppm) and Fe (6.70 %). [Pb and Zn were below the threshold level in the re-analysed split].

Values for all of the above elements were below threshold levels in the basal till sample from follow-up site MV-W09b, about 750 m to the south-southwest of the original site. In contrast, the basal till sample from follow-up site MV-W09c, about 800 m northeast of the original site, was anomalous in Sb (4.8 ppm) and returned threshold values for As (49.7 ppm), Co (27 ppm) and Cu (67 ppm).

The pebble sample from site MV-W09b is dominated by clasts of distal derivation, resembling those noted in the samples from the Bear and Northeast lakes area. In contrast to the 'b' site, the pebble sample from site MV-W09c is dominated by wackes and slates derived from the local Silurian Burtts Corner Formation, as is the pebble sample from the 'a' site. This data suggests that the anomalies represent mineralization present in bedrock in the local area

## DISCUSSION

Seaman (1997, p. 237) stated that "elevated Cu, Pb, and Zn values do not appear to be associated with most of the known mineral occurrences in the Millville East area," i.e., the known mineralization is not showing up as anomalies in the near-surface sampling, though it is no doubt contributing to the high background values in Millville East. Also, the follow-up sampling documented above suggests that the near-surface till anomalies are of very limited areal extent in this half of the map area. This geochemical phenomenon may result from the mode of till deposition in the area, and the consequences and limitations of till sampling by hand at a fixed depth below the surface.

An estimation of glacial transport distance is important in understanding the origin of the geochemical anomalies, and their absence around many of the known mineral occurrences. The Carboniferous Carlisle Formation, comprising red clastic sedimentary rocks, outcrops in the extreme north-central part of the map area and in the Coldstream (NTS 21 J/6) map area to the north, and comprises an ideal marker unit. A dispersal train of reddish-coloured basal till extends south-southeastward from this rock unit to the southern boundary of the Millville map area, a distance of more than 25 km. Similarly, elevated concentrations of volcanic clasts derived from the Costigan Mountain and Wapske formations and the Tetagouche Group form an irregular dispersal train extending across the Pokiok Batholith and the Burtts Corner Formation into the southeastern part of the map area. This indicates dispersal of fine-grained material in the Millville East area for distances in the order of 30 km, and of coarser material for at least half that distance. Dispersal distances of similar magnitude (and trend) have been reported for the Fosterville (NTS 21 G/13) and Forest City (NTS 21 G/12) map areas to the southwest (Seaman 1995).

At site MV-Q14, the roadcut section exposes approximately 0.4 m of mineral soil (i.e., not including the uppermost layer comprising the organic litter) overlying about 0.7 m of the dark reddish brown till, which in turn overlies at least 0.6 m of yellowish brown till. To the eye, this appears to be a multiple till site. However, till fabric measurements, geochemical analyses and pebble lithology data indicate that only one till is present. [Peak till fabric trend in both the upper and lower units is about  $160^\circ$ ; calculation, for each element, of the percent deviation from the mean for the two samples returned values that lie within the range noted for the eleven field duplicate samples from the Millville map area (except for Cs, for which the deviation was somewhat greater; and for La and Rb, for which the deviation was less!); and the till pebble lithology results are markedly similar (91% sedimentary, 8% volcanic and 1% quartz for the upper sample; 84% sedimentary, 2% granitic, 11% volcanic and 2% quartz for the lower)]. The indication is that the glacier flowed south-southeastward across this site for sufficient time to deposit a till that was an admixture of material derived from the various pre-Carboniferous rock units lying within 25 km to the north-northwest, and to subsequently deposit about a metre of similar till to which reddish-coloured fine material derived from the Carlisle Formation had been added. Therefore, only one till sheet is present, but one which becomes increasingly more distal in character with distance above the bedrock surface. A similar observation has been noted for the Forest City (NTS 21 G/12) map area, which lies completely within the limits of the Pokiok Batholith, where the concentration of granitic clasts in the till was observed to be greatest in till directly overlying bedrock (Seaman 1992).

As a consequence, where the till is thick, samples collected at the normal near-surface sampling depth of 0.4 to 0.7 m below the top of the mineral soil contain a significant proportion of distal material. If the thick till site is proximal to a mineral occurrence, the occurrence will not be represented by the geochemistry of the sample. Under glacial transport, material from a mineral occurrence will be deposited at progressively higher levels within the till in the down-ice direction (see: DiLabio 1990, Figure 1). If the till is very thick, mineralized material that finally reaches the sampling depth is too dispersed and diluted by non-mineralized material to stand out as a distinct anomaly. However, such samples are representative of the bedrock geochemistry on a regional scale, and account for the elevated background values of base metals in the Millville East area (i.e., this is a regional characteristic, as mineralization is common in the area). However, samples from the upper parts of thick tills in this area are not representative of the local bedrock nor of any mineralization that may lie within it, and thus cannot aid in targeting specific mineral occurrences.

In contrast, where the till is thin, it is probable that the sample collected will be of more local derivation and, hence, more representative of the underlying bedrock and any mineralization that it may contain. A couple of the anomalous sites in the Millville map area directly overlie bedrock, and several occur in close proximity to bedrock outcrops and thus probably in thin till. In addition, the pebble samples from many of these anomalous sites appeared to contain more clasts of probable local derivation than did the samples from the neighbouring, non-anomalous, follow-up sites. Hence, the absence of anomalies at the follow-up sites may not relate to absence of mineralization in the underlying rock, but rather to the sample being taken from material of predominantly distal derivation. A similar situation was encountered at the Dead Creek Pb-Zn-quartz float site in the Fosterville map area, where a distal basal till, only anomalous in As and threshold in Ni and Pb, overlies a local deformation till that is anomalous to extremely anomalous in Au, As, Co, Cu, Fe, Pb, Sb and Zn (Seaman 1996).

The main objective of a regional till sampling program is to define regional threshold levels for the various economic elements. It is for that reason that extreme high values are deleted before calculation of the mean and standard deviation, as noted above. Hence, it is not necessary that anomalies be identified,

though the identification of anomalies, such as the multi-site Au anomaly at Poplar Mountain (Seaman 1994) or the As-Sb dispersal train in the north-central part of the Millville map area, is a definite bonus. To obtain samples that would specifically target local mineralization would require excavation to bedrock and sampling of the basal till directly above the bedrock surface. Such excavation would be impractical to impossible by hand in areas of thick till, and prohibitively expensive by mechanical means for the type of regional survey currently being undertaken. However, it would certainly be warranted for detailed exploration in areas where bedrock mineralization was known to occur, or around till anomalies in areas with high mineral potential (along with direct sampling of the underlying bedrock).

## CONCLUSIONS

Re-analysis of the original anomalous samples (duplicate splits) confirmed the anomalies identified by the sampling on the 2 km grid. However, of the 34 follow-up samples, only four returned anomalous values, and only a further seven returned threshold values. The lack of elevated values in most of the follow-up samples may relate to the extensive glacial dispersal that has occurred in the area, with material being mixed and transported over a distance of several tens of kilometres before being deposited. Where the till is thick, the samples collected within the limitations of hand excavation are commonly taken from the part of the till that contains a significant proportion of distal material. They are thus more representative of the regional geochemistry than they are of local bedrock mineralization. The till anomalies that do occur tend to be associated with sites where the available evidence suggests that the till is thin, and thus the sample obtained is of material that is of more local derivation.

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## GEOLOGY OF THE TAYLOR BROOK MASSIVE-SULPHIDE DEPOSIT (NTS 21 O/08E), BATHURST MINING CAMP, NEW BRUNSWICK ‡

J.A. Walker

New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch,  
P.O. Box 50, Bathurst, New Brunswick, CANADA E2A 3Z1 (e-mail: jawalker@gov.nb.ca)

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The Taylor Brook Zn-Pb massive sulphide deposit is hosted within an intercalated sequence of felsic ash and lapilli tuff, aphyric to sparsely feldspar-phyric rhyolite flows, hyaloclastite, and minor sedimentary rocks of the Flat Landing Brook Formation. The deposit has a strike length of approximately 650 m and a down-dip extent of greater than 600 m. The surface trace of the deposit is tadpole-shaped with the thickest accumulation of sulphides at shallow (<50 m) depths in the western part of the deposit.

The sulphide zone comprises one to four stratabound horizons of heavily disseminated to semi-massive and/or massive sulphides interlayered with hydrothermally altered volcanic rocks. The upper and lower contacts of individual sulphide horizons vary from diffuse to sharp. Sulphide mineralogy, in order of decreasing abundance, is: pyrite, pyrrhotite, sphalerite, galena, and chalcopyrite. Metal zonation, i.e., Zn+Pb-rich tops and Cu-rich bases, is locally developed at the scale of individual horizons or on the scale of total deposit thickness. The Cu/Pb/Zn ratio for the deposit is 0.1/1/2 and is consistent with the Pb/Zn ratios from other deposits in the Bathurst Mining Camp. A well-developed chalcopyrite-pyrrhotite stringer zone occurs below the stratabound sulphide horizon (north side of lens), and is particularly well developed at depth in the western part of the deposit. Hydrothermal alteration is developed in both footwall and hanging-wall rocks. Footwall alteration is denoted by development of moderate to locally abundant chlorite, whereas hanging-wall alteration is characterised by white micas or minor chlorite. The relative position of stratabound and stringer-type mineralization, and variable footwall and hanging-wall alteration suggests that the deposit dips to the south, is right-way up, and is part of a proximal autochthonous system.

Le gîte de sulfures massifs de Zn-Pb de Taylor Brook se trouve à l'intérieur d'une séquence intercalée de cendres felsiques et de conglomérat volcanique à lapilli dans une matrice fine, d'écoulements de rhyolite aphyrique à légèrement porphyro-feldspathique, d'hyaloclastite et d'une faible quantité de roches sédimentaires de la Formation de Flat Landing Brook. Le gîte s'étend sur une longueur d'environ 650 mètres et son aval pendage s'enfonce à plus de 600 mètres. Les traces en surface du gîte présentent un profil têtard dans lequel l'accumulation la plus épaisse de sulfures à faible profondeur (< 50 m) a été relevée dans la partie occidentale du gîte.

‡ Contribution to the EXTECH-II program (New Brunswick Geological Surveys Branch ordinary budget).

La zone de sulfures est constituée d'un à quatre horizons stratiformes de sulfures très dispersés à semi-massifs ou massifs interstratifiés avec des roches volcaniques soumises à une altération hydrothermale. La délimitation des zones de contact supérieure et inférieure de chacun des horizons de sulfures varie d'une séparation diffuse à une séparation bien nette. La teneur minéralogique des sulfures se présentent comme suit, selon l'ordre décroissant d'abondance des éléments: pyrite, pyrrhotine, sphalérite, galène et chalcopryrite. La zonation des métaux, c.-à-d. les sommets riches en Zn+Pb et les bases riches en Cu, s'est développée localement à l'échelle de chacun des horizons ou à l'échelle de toute l'épaisseur du gîte. Le rapport Cu/Pb/Zn du gîte est de 0,1/1/2, ce qui correspond au rapport Pb/Zn des autres gîtes du Camp minier de Bathurst. On relève un chapelet bien développé de chalcopryrite-pyrrhotine au-dessous de l'horizon stratiforme de sulfures (nord de la lentille), qui est particulièrement développé en profondeur dans la partie occidentale du gîte. L'altération hydrothermale s'est répandue dans les roches de l'éponte inférieure et de l'éponte supérieure. L'altération de l'éponte inférieure transparait dans l'apparition d'une quantité moyenne à localement abondante de chlorite, tandis que l'altération de l'éponte supérieure se caractérise par la présence de muscovite et d'une faible quantité de chlorite. L'emplacement relatif de la minéralisation stratiforme et transversale et l'altération variable des épontes inférieure et supérieure permettent de supposer que le gîte s'incline vers le sud, qu'il est vertical et qu'il fait partie d'un réseau autochtone proximal.

## INTRODUCTION

The Taylor Brook deposit, Unique Record Number (URN) 0400, is in the polydeformed Middle Ordovician Tetagouche Group, one of three predominantly volcanic groups that comprise the Bathurst Mining Camp at the northeast end of the Miramichi Anticlinorium (Figure 1). The deposit is hosted within an intercalated sequence of felsic ash and lapilli tuff, rhyolite flows and related rocks assigned to the Flat Landing Brook Formation, which is the stratigraphically higher of two dominantly felsic volcanic units in the Tetagouche Group.

Most of the exploration in the Bathurst Mining Camp has focused on the Tetagouche Group, specifically the contact between the Flat Landing Brook Formation and underlying Nepisiguit Falls Formation (both felsic volcanic units). This horizon, known as the Brunswick Horizon, hosts many of the more famous deposits in the Bathurst Mining Camp including the Brunswick No. 6 and No. 12 and Half Mile Lake deposits (McCutcheon *et al.* 1993 and others). Because so much of the historical exploration effort has focused on the Nepisiguit Falls–Flat Landing Brook contact, other prospective horizons have received relatively little attention. However, economically viable sulphide mineralization was discovered and exploited from two deposits within the Flat Landing Brook Formation, namely: Stratmat Boundary (891 000 t of 3.31% Pb, 7.96% Zn, 0.32% Cu and 44 g/t Ag), and Heath Steele N-5 (330 000 t of 3.24% Pb, 7.15% Zn 0.33% Cu and 37 g/t Ag) deposits (Hamilton 1992).

The potential for mineralization within the Flat Landing Brook Formation coupled with its relatively under-explored status necessitates an attempt to discern the tectonostratigraphy and the paleo-environmental controls on sulphide deposition and related alteration in the known deposits in order to aid future exploration initiatives. The recent discovery of the Taylor Brook deposit (Burton 1978; Gummer 1978), coupled with abundant good-quality core from extensive drilling programmes conducted by Stratabound Minerals Corp. (Lutes 1996) and others, made the Taylor Brook deposit ideal for this study.

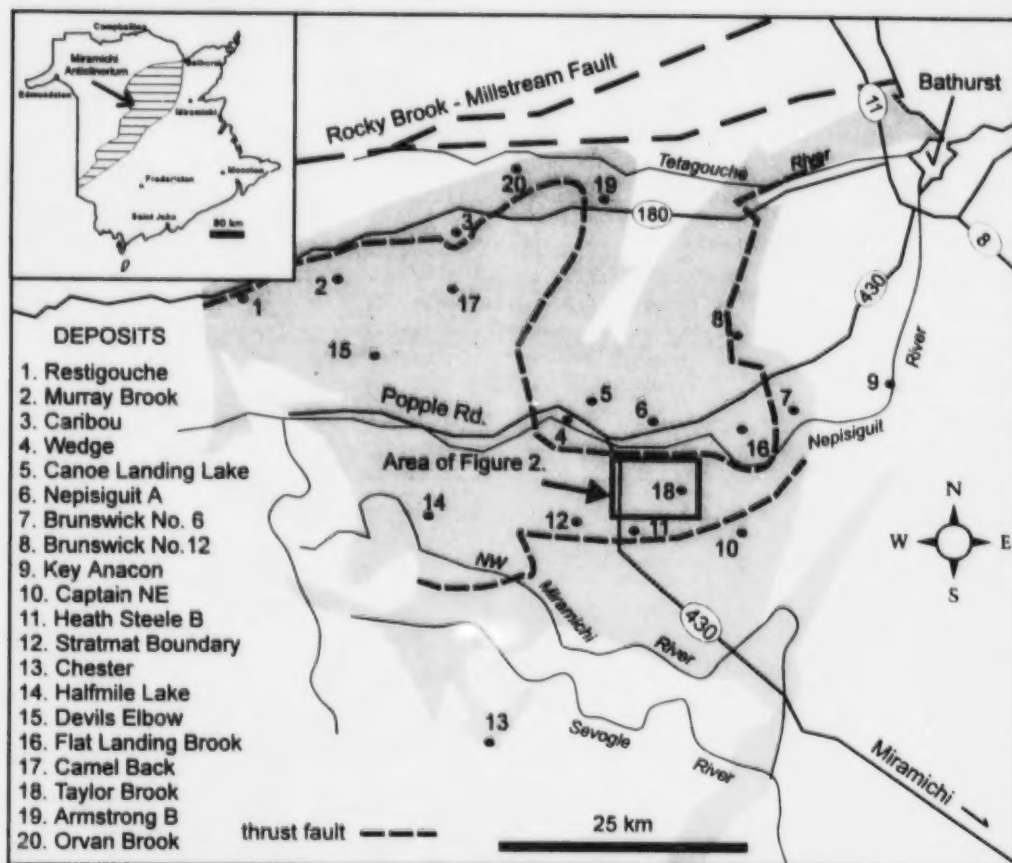


Figure 1. Location of the Taylor Brook deposit with respect to the Bathurst Mining Camp (shaded) and major massive-sulphide deposits (modified from McCutcheon 1997). Note the thrust faults bounding the nappe that hosts the Taylor Brook deposit. The detailed geology in the vicinity of the deposit is outlined in Figure 2.

## LOCATION AND WORK HISTORY

The Taylor Brook deposit is located in the eastern part of the California Lake map area (NTS 21 O/08), approximately 35 km south-southwest of the city of Bathurst (Figure 1), and 3 km east-southeast of the intersection of Route 430 and the Taylor Brook road (Figure 2).

Consolidated Morrison Ltd. discovered the Taylor Brook deposit in 1977 during follow-up work on a pulse-electromagnetic geophysical anomaly. Subsequent drilling of the "discovery hole" intersected 0.36% Pb, 2.15% Zn and 0.53 oz./ton (18.2 g/t) Ag over 3 m. Stratabound Minerals Corp. acquired the property in 1987 and calculated that the deposit comprises 325 000 t grading 2–3 % (Pb+Zn) and 0.4 oz./ton (13.7 g/t) Ag (*Northern Miner*; April 1988). In 1991, Teck Corporation optioned the property and drilled two holes; the best assay from this work was 1.11% Zn, 0.54% Pb and 0.41 oz./ton (14.1 g/t)

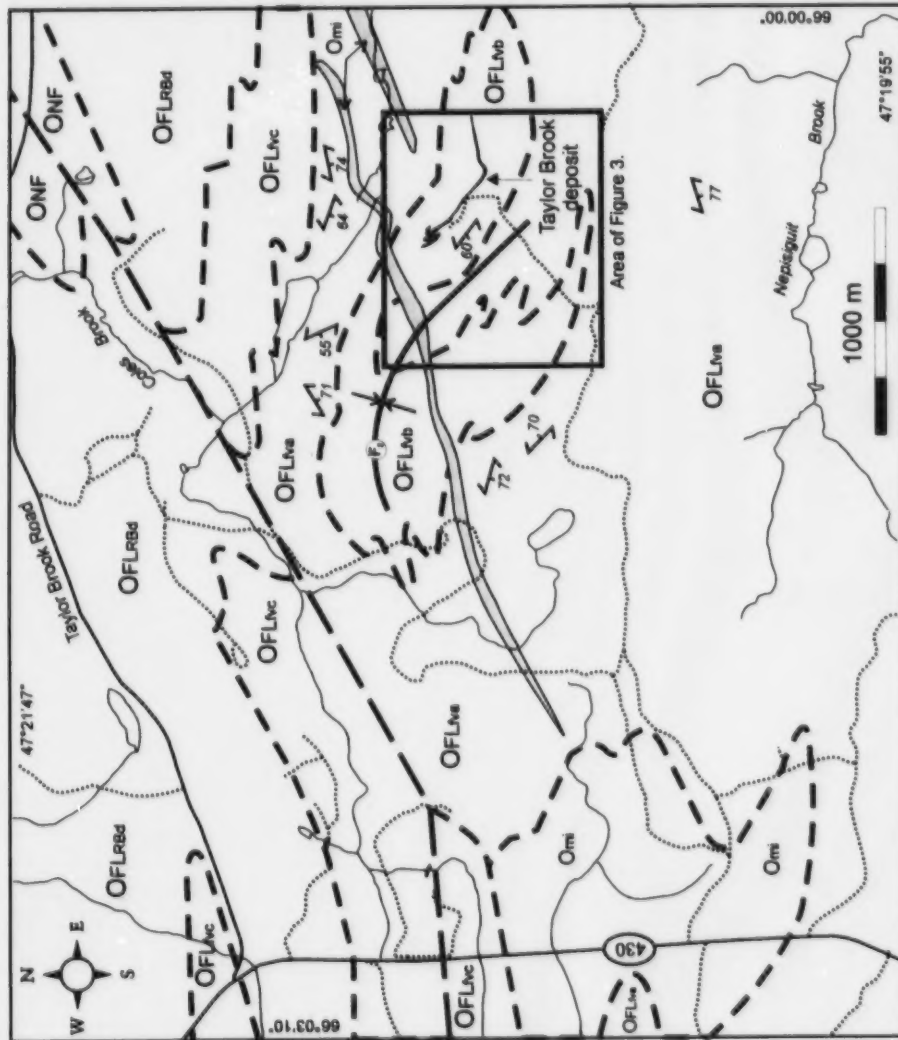


Figure 2. Geology in the vicinity of the Taylor Brook deposit showing deposit location with respect to roads, streams, and regional geological contacts.

## LEGEND

### ORDOVICIAN

Omi gabbro and diabase

### TETAGOUCHE GROUP

#### Fiat Landing Brook Formation

OFLrb Roger Brook Member: Greyish green pyroclastic rocks (feldspar-crystal tuff, crystal-vitric tuff, and lithic-crystal tuff) and local related tuffaceous sedimentary rocks; minor pink or buff massive "cherty" rhyolite, basalt, and dark grey shale.

OFLvc Grey to greenish grey, potassium feldspar-phyric rhyolite, minor aphyric rhyolite and hyalodastite.

OFLva Felsic hyalodastite breccias and related tuff and volcanoclastic sedimentary rocks; minor massive aphyric rhyolite.

OFLvb Grey to greenish grey aphyric rhyolite; minor feldspar-phyric rhyolite, hyalodastite breccias or tuffs, and sedimentary rocks.

#### Nepisiguit Falls Formation

ONF Quartz-feldspar crystal tuff, locally contains clasts or thin beds of red shale or chert minor quartz-feldspar porphyry, feldspar-crystal tuff and basalt.

--- geologic contact

• fault

— main road

..... logging road

○ pond, stream

↖ cleavage

✕ syndine

Geology modified from Wilson (1993a)

Table 1. Summary of Diamond-drill Holes in the Taylor Brook Deposit (URN 0400)

Hole Name	Company	Easting	Northing	Elevation (m)	Azimuth	Dip	Length (m)
CM-77-1	Consolidated Morrison	337028	894206	0	0	-45	36.8
CM-78-1	Consolidated Morrison	337301	894252	0	0	-50	66.14
CM-78-2	Consolidated Morrison	337221	894248	0	0	-50	119
CM-78-3	Consolidated Morrison	337133	894209	0	0	-50	98.14
CM-78-4	Consolidated Morrison	337223	894161	0	0	-60	194
CM-78-5	Consolidated Morrison	337133	894136	0	0	-60	160
JDO-86-1	Granges	336970	894179	0	45	-60	132.89
JDO-86-2	Granges	336911	894134	0	45	-60	91.4
TBD-92-01	Teck Corp.	337224	894057	0	0	-70	278.89
TBD-92-02	Teck Corp.	336911	894134	0	45	-70	214.58
TBD-96-17	Stratabound Minerals Corp.	336599	893973	0	45	-79	440.4
TBD-96-18	Stratabound Minerals Corp.	336666	893893	0	45	-90	480.67
TBD-96-19	Stratabound Minerals Corp.	336504	893897	0	45	-80	514.8
TBD-96-20	Stratabound Minerals Corp.	336568	894095	0	45	-80	410.57
TBD-96-21	Stratabound Minerals Corp.	336386	894190	0	45	-80	446.23
TBD-96-22	Stratabound Minerals Corp.	336675	893968	0	45	-80	453.24
TBD-96-23	Stratabound Minerals Corp.	336737	894191	0	45	-70	260
TBD-96-24	Stratabound Minerals Corp.	336802	893951	0	0	-80	395.33
TBD-96-25	Stratabound Minerals Corp.	336766	894113	0	45	-70	427.94
TBD95-01	Stratabound Minerals Corp.	336875	894404	0	45	-45	129.5
TBD95-10	Stratabound Minerals Corp.	336788	894353	2	45	-70	101.8
TBD95-11	Stratabound Minerals Corp.	336806	894333	2	45	-70	111.56
TBD95-12	Stratabound Minerals Corp.	336767	894297	3	45	-70	135.94
TBD95-13	Stratabound Minerals Corp.	336788	894457	2	45	-45	101.8
TBD95-14	Stratabound Minerals Corp.	336776	894516	1	45	-45	101.8
TBD95-15	Stratabound Minerals Corp.	336859	894420	1.5	45	-45	98.76
TBD95-16	Stratabound Minerals Corp.	336708	894096	0	45	-70	320.65
TBD95-02	Stratabound Minerals Corp.	336864	894381	0	45	-45	70.1
TBD95-03	Stratabound Minerals Corp.	336841	894368	0	45	-45	138.4
TBD95-04	Stratabound Minerals Corp.	336841	894368	0	45	-45	163.4
TBD95-05	Stratabound Minerals Corp.	336839	894403	0	45	-45	138.38
TBD95-06	Stratabound Minerals Corp.	336823	894424	0	45	-45	121.92
TBD95-07	Stratabound Minerals Corp.	336876	894366	0	45	-45	123.14
TBD95-08	Stratabound Minerals Corp.	336823	894388	2	50	-45	116.4
TBD95-09	Stratabound Minerals Corp.	336823	894388	2	50	-70	124.36

Ag over 3.13 m (Miller 1993). Work on the deposit, from its discovery up to and including that conducted by Teck Corp. (Miller 1993), tested the east end of the deposit to vertical depths of about 200 m, along a strike length of 325 m.

Most recently, Lutes (1996) reported on diamond drilling (25 holes) that focused on the western part of the property. This work was successful in extending the limits of known mineralization 300 m farther to the northwest and to vertical depths of 425 m. However, grade and tonnage figures for the deposit, including this recent work, have not been published. In total, 35 holes have been drilled at the Taylor Brook sulphide deposit (Table 1). The most recently drilled core is from work conducted by Stratabound Minerals Corp. and comprises 25 diamond-drill cores (Figure 3) totalling 2 739.6 m, all of which are stored at the Madran core storage facility.

Outcrops are abundant to the south and west of the deposit but, in the vicinity of the deposit and to the north, outcrop is sparse. Consequently, work conducted during this study was concentrated on diamond-drill cores.

## GEOLOGICAL SETTING

The Tetagouche Group (Figure 4) volcano-sedimentary sequence is interpreted to have been deposited in a back-arc-basin environment, on a continental flysch sequence of the Miramichi Group (cf. van Staal and Fyffe 1991; and McCutcheon *et al.* 1993). The only unit that occurs in the study area is the Flat Landing Brook Formation and thus is the only unit described below. Descriptions of the other units can be found in Wilson (1993b), and the structure is described in van Staal and Fyffe (1991) and McCutcheon *et al.* (1993).

The Taylor Brook deposit occurs within the Flat Landing Brook Formation, the stratigraphically higher of two felsic volcanic units in the Tetagouche Group. The internal stratigraphy of the Flat Landing Brook Formation in the study area is described in the following section.

### *Stratigraphy*

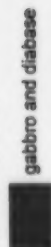
The Flat Landing Brook Formation forms the uppermost felsic volcanic unit in the Tetagouche Group (van Staal and Fyffe 1991; Wilson, this volume). Elsewhere, rhyolite from this formation has yielded a U–Pb zircon age of  $466 \pm 2$  Ma (Rogers *et al.* 1997), which is consistent with earlier age estimates and its interpreted position in the regional tectonostratigraphic framework.

The Flat Landing Brook Formation was divided into several units by Wilson *et al.* (1998), reflecting different facies of the volcano-sedimentary sequence. Two of these are present in the study area. The Taylor Brook deposit occurs within unit OFL<sub>IVb</sub> (Figure 3) that comprises an intercalated sequence of grey to green felsic hyaloclastite, lithic and crystal-lithic tuff, massive grey, green or red aphyric rhyolite flows, and minor sedimentary rocks. It should be emphasized that the stratigraphic position of unit OFL<sub>IVb</sub> within the Flat Landing Brook Formation (i.e., lower, middle or upper part) is uncertain.

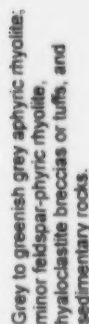
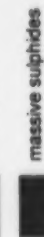
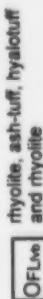
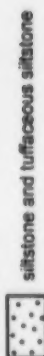
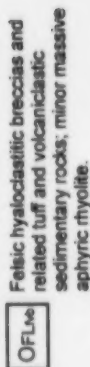
Unit OFL<sub>IVb</sub> is bounded above and below by unit OFL<sub>IVa</sub>, consisting of grey to greenish grey aphyric rhyolite, local feldspar-phyric rhyolite, hyaloclastite breccia, tuff, and very minor sedimentary rocks (Wilson 1993a).

# LEGEND

## ORDOVICIAN



## Flat Landing Brook Formation



Units OFLva and OFLvb are from mapping by Wilson (1993b), see Figure 2 for descriptions. Detailed contacts are compiled and modified from Lutes (1996).

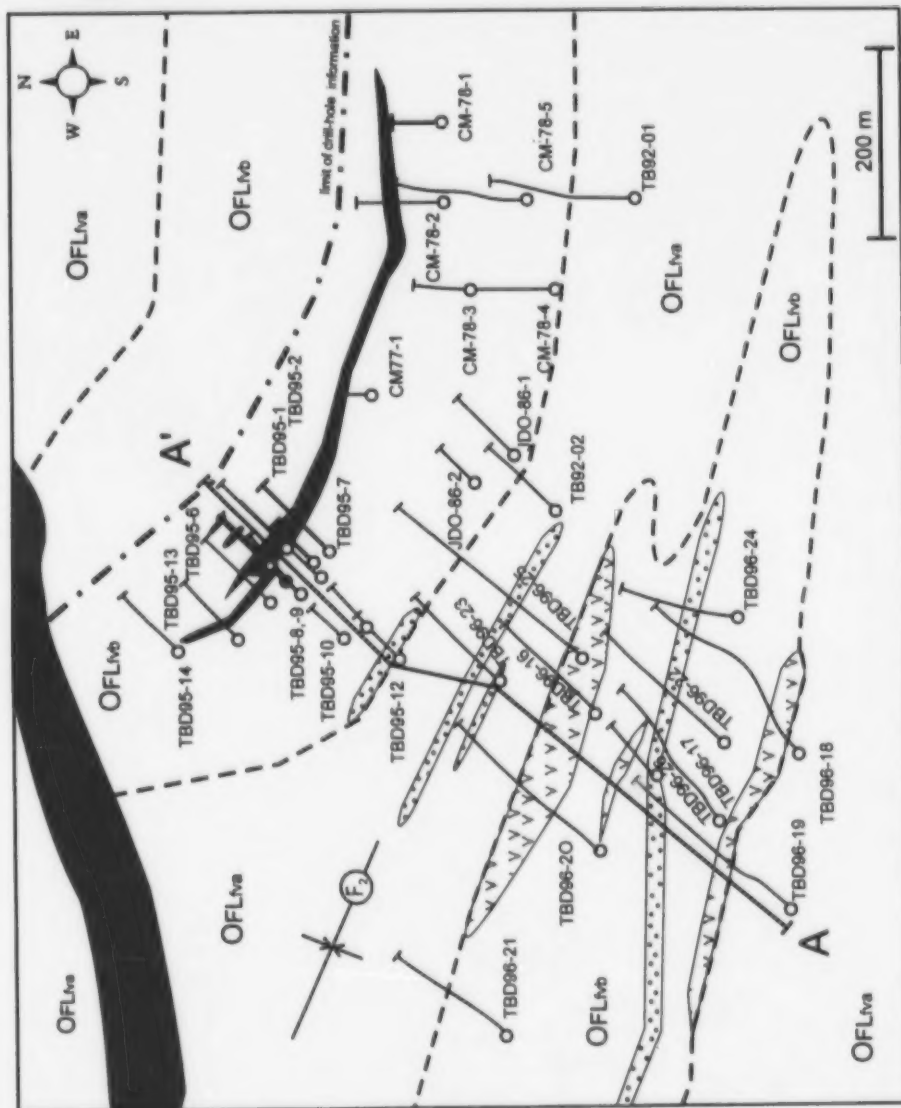
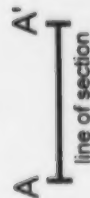


Figure 3. Geology in the vicinity of the Taylor Brook deposit showing drill-hole locations. Line of section labelled A-A' is presented in Figure 5. Compiled from Wilson (1993a) and Lutes (1996).



## Structure

The thrust nappe, hosting the Taylor Brook deposit (Figure 1), comprises an overall north-facing conformable (?) sequence of rocks belonging to the Tetagouche Group (Lentz and Wilson 1997; Wilson 1993a, b). The base of this nappe occurs in the Heath Steele area where the Nepisiguit Falls Formation is in thrust contact with Flat Landing Brook rocks farther to the south. The Nepisiguit Falls rocks young northward into the Flat Landing Brook Formation, which hosts the Taylor Brook deposit (Lentz and Wilson 1997). Overall, this sequence is north facing but local reversals due to folding are known to occur (Wilson 1993a, b). For a more detailed discussion of regional tectonostratigraphy, refer to van Staal and Fyffe (1991) and McCutcheon *et al.* (1993).

An accurate structural interpretation of the rocks in the study area (Figure 3) is difficult to formulate due to low outcrop density, apparent rapid facies changes in the volcanic pile, and the absence of a good marker horizon. However, some generalizations can be made using the distribution of rocks hosting the Taylor Brook deposit. Mapping by Wilson (1993a) and Lutes (1996) suggest that the host unit (OFL<sub>fb</sub>) is folded into a tight syncline with an axial plane oriented toward the west-northwest, and that the deposit is situated within the northeast limb of this fold. This fold orientation is somewhat consistent with the  $S_1$ - $S_2$  cleavage measurements. However, the map pattern is based primarily on rock-type distribution rather than on interpretation of structural data (Wilson, personal communication, 1999).

Drill cores confirm the presence of the one strong  $S_1$ - $S_2$  composite cleavage, and consistent core/fabric angles show that this cleavage has vertical continuity, i.e., recumbent  $F_3$  folding has not significantly re-oriented the earlier  $S_1$ - $S_2$  fabric. This fabric is consistent on the deposit scale, and consistent with the inferred position of the deposit on the limb of a fold. Right-way-up indicators in this sequence are few, and are restricted to graded bedding and sharp coarse-fine (erosional) contacts between tuff and siltstone beds in the hanging wall, and are consistent with a south-younging sequence. However, some of these intervals also display graded beds that suggest younging to the north, at least on the local scale. The south-facing scenario is preferred because it is corroborated by stringer-mineralization and metal-zonation trends, as described below.

## DEPOSIT GEOLOGY

### Footwall rocks

All of the holes in the Taylor Brook deposit are drilled toward the north or northeast because of the south-dipping attitude of the sulphide horizon. Consequently, the footwall stratigraphy is not well known because most drill holes did not penetrate beyond the massive sulphide horizon (Figure 5). Drill hole TB96-25 penetrates the farthest into the footwall sequence and ends in grey to red, massive to locally highly spherulitic, aphyric rhyolite (Figure 6a) and intercalated thin beds of fine-grained tuff and rhyolite-clast fragmental rocks, some of which may be interpreted as hyaloclastite. Locally, the footwall rhyolite contains sparse fine (<1 mm) feldspar phenocrysts. The feldspars in these flows are similar in size and concentration to the feldspars in the crystal-lithic tuff that occurs higher in the sequence and may have been derived from the same magma chamber. Lutes (1996) reports that fine-grained feldspar-phyric rhyolite is the dominant footwall rock type intersected in many of the holes at depth in the western part of the deposit (unit OFL<sub>fa</sub> on Figures 3 and 5). In contrast to the overlying intensely altered tuffs (part of unit OFL<sub>fb</sub> on Figures 3 and 5), the rhyolite is only weakly altered.

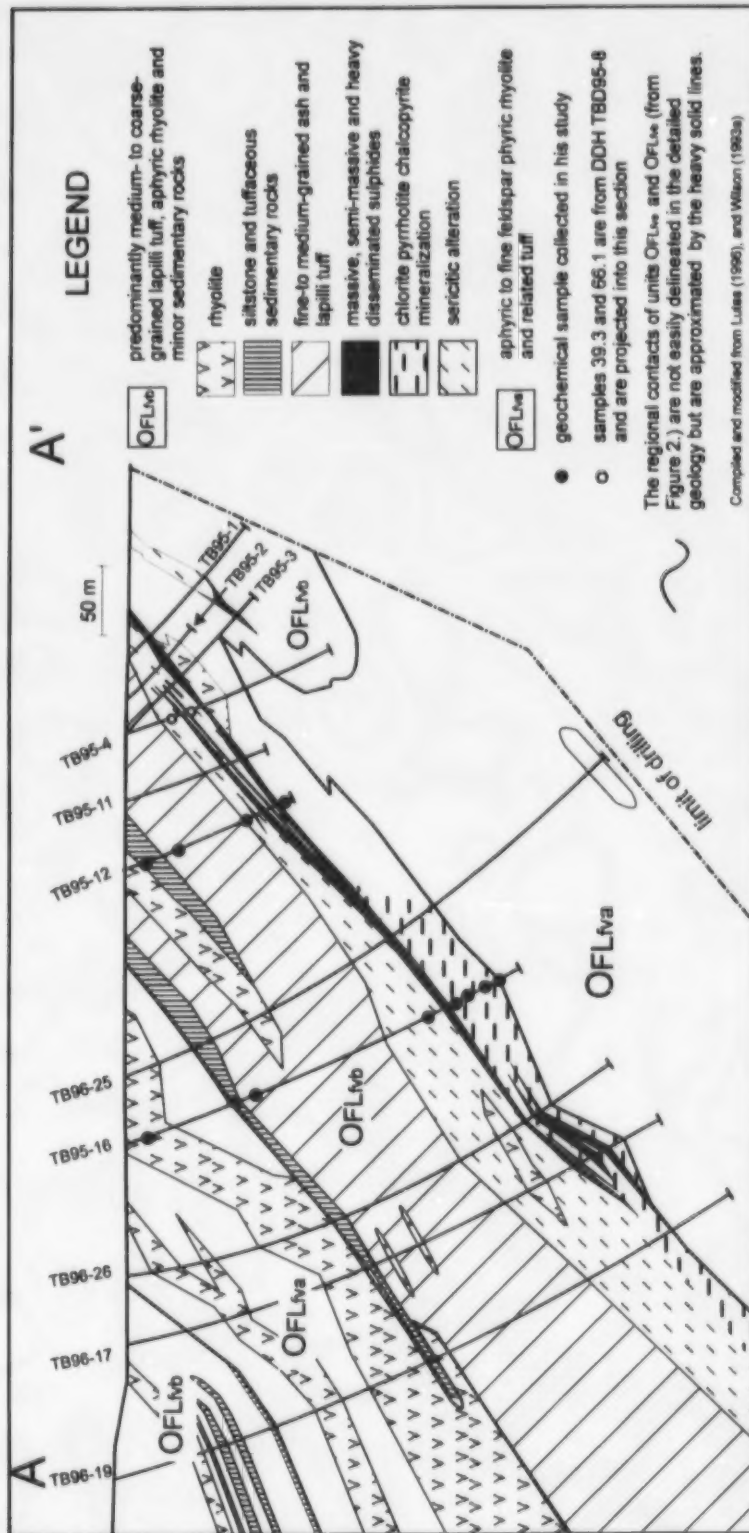


Figure 5. Cross-section through the Taylor Brook deposit. Line of section A-A' is located on Figure 3.

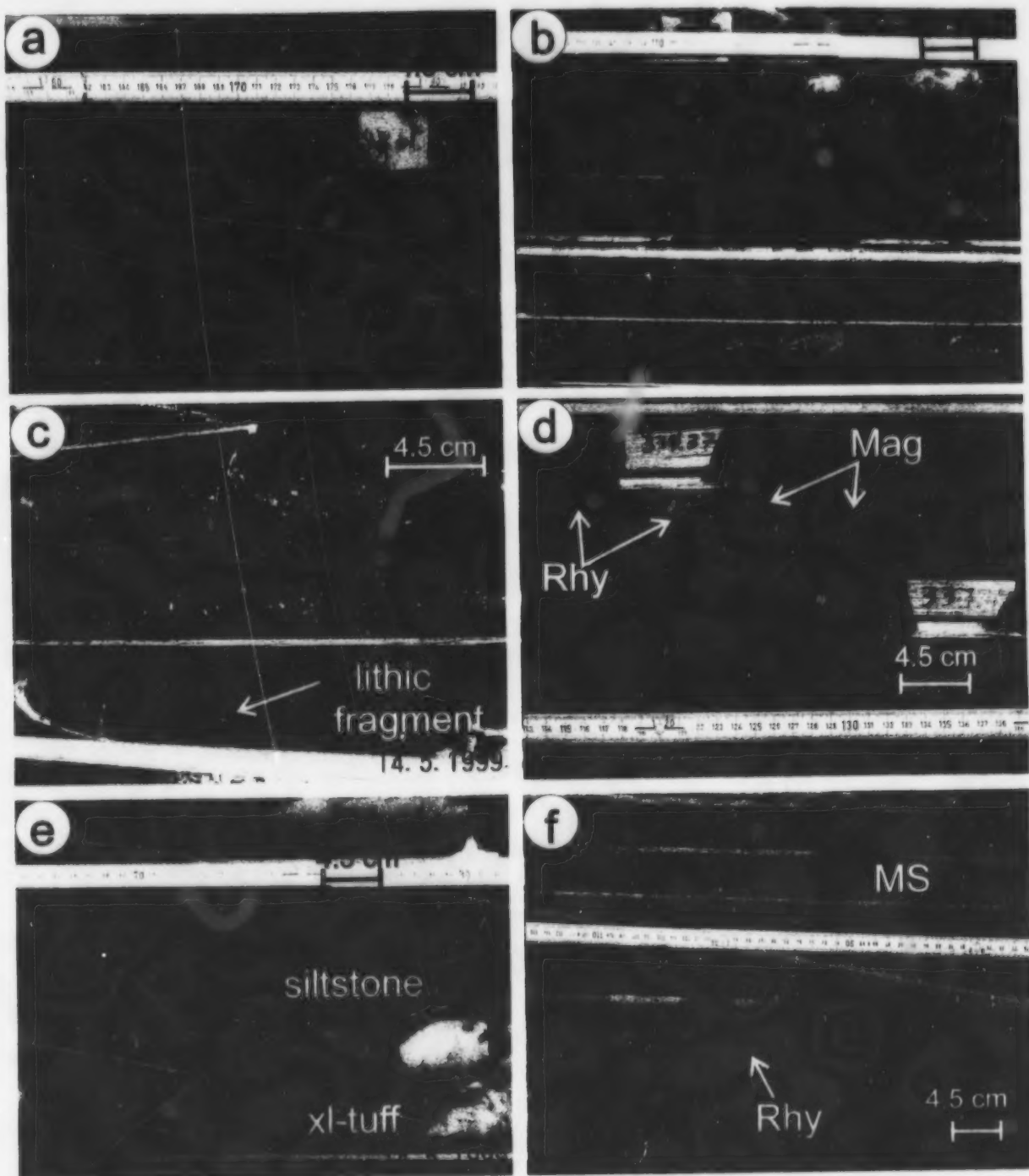


Figure 6. Representative rock types from the Taylor Brook deposit. (a) Red massive and spherulitic rhyolite from the footwall; (b) red to grey, massive to spherulitic hanging-wall rhyolite; (c) crystal tuff with lithic fragment from the hanging wall; (d) lithic tuff containing rhyolite (Rhy) and magnetite (Mag) clasts interlayered with ash and crystal tuff (334 m, drill hole TBD97-17); (e) interlayered siltstone and crystal tuff in hanging wall; (f) massive sulphides (MS) grading upward into ash tuff; note the rhyolite "bomb" (Rhy) in the tuff. Top is toward the bottom of photo.

The rhyolite grades upward into an interlayered sequence of greenish yellow lapilli tuff (fragments of 0.1 to 0.5 cm in long dimension) and ash tuff with weak to moderately strong sericite and/or chlorite alteration in the matrix (part of unit OFL<sub>fvb</sub> on Figures 3 and 5). The intensity of sericite and chlorite development increases up-hole, where weakly sericitic tuff grades rapidly into dark green, pervasively chloritized tuff. In some places, alteration is so intense that the rock is almost entirely chlorite with only a few small vestiges of the protolith remaining. Locally, the chloritic rocks are cut by pyrite–pyrrhotite–chalcopyrite veins that are interpreted to represent stringer-type mineralization (see section on mineralization). The intensely chloritic zone grades upward into the exhalative massive-sulphide zone. The contact between the footwall sequence and the sulphide zone is generally sharp but may locally be gradational on a centimetre scale.

### ***Hanging-wall rocks***

The hanging-wall sequence is similar to the footwall in that it is dominated by an assortment of grey to greenish grey and red aphyric to locally spherulitic rhyolite flows (Figure 6b) and related breccias. Crystalline, ash, and lapilli tuff (Figures 6c, d, and e), are also common in the hanging-wall sequence, and rhyolite fragments or bombs (up to 20 cm) are locally present in the fine-grained volcanic rocks (Figure 6f). Most of these are interpreted to be volcanic because of the presence of heterolithic clasts, broken crystals, and locally developed bedding. However, some of these rocks, particularly the rhyolitic clast-rich fragmental rocks, may be hyaloclastic breccia as interpreted by Wilson (1993b). The hanging-wall sequence also contains thin beds of intercalated greenish grey to brown siltstone and tuffaceous siltstone, which have not been recognized in the footwall (Figure 6e).

On a broad scale, there seems to be a slight vertical gradation in fragment size of the felsic volcanoclastic rocks in the hanging wall. Fine-grained ash and lapilli tuff in the immediate hanging wall pass into coarser volcanoclastic material at higher stratigraphic levels. Aphyric rhyolite flows are more intimately associated with the coarse-grained volcanoclastic rocks than with the fine-grained ones (Figures 4 and 5). Throughout the hanging-wall sequence, veinlets and veins (<1 cm in width) of pyrite and, more rarely, pyrite ± galena ± sphalerite occur locally.

Within the hanging-wall sequence, zones of weak to moderately intense sericitic alteration and weak to intense chloritic and locally siliceous alteration are developed up to 200 m above the sulphide horizon (Figure 5). The relationship between the deposit and these hanging-wall alteration zones is not clear, but may represent the effects of waning hydrothermal activity coincident with units of high primary permeability that postdate burial of the sulphide deposit. In some places, chlorite is present as veins (maximum 2 cm wide) that cut the hanging-wall sequence. Milky white quartz and quartz–feldspar veins are also present in the hanging wall and probably formed in response to deformation rather than syn-depositional mechanisms.

### ***Exhalite horizon***

The exhalite horizon comprises one to four stratabound sulphide-rich horizons interlayered with chloritic ash tuff. The surface trace of the Taylor Brook deposit (Figures 2 and 3) is tadpole-shaped with a sulphide zone that has a known strike length of approximately 650 m and down-dip extent of up to 630 m. Sulphide-rich beds are interlayered with variably altered felsic volcanic and volcanoclastic rocks. The combined thickness of sulphides and interlayered tuffs is typically 3–4 m (Lutes 1996) but can be as much as 65 m (drill hole TBD95-5). The thickest accumulation of sulphides is in the northwestern part of the deposit, where several sulphide layers coalesce at a shallow depth of less than 50 m (Figure 5). Here, the deposit

strikes  $115^{\circ}$  and extends down dip to a vertical depth of at least 425 m (Lutes 1996). To the east, the strike of the deposit changes to  $090^{\circ}$ , dips consistently to the south at approximately  $45^{\circ}$ , and thins rapidly with depth. To the east, and to the west at depth, the exhalative zone thins to one horizon of 2–4 m in thickness. The contact between the sulphide zone and the underlying chloritic tuffs is commonly sharp, but may be gradational. The sharp contacts probably reflect a period when deposition of tuffaceous sediment was minimal or non-existent relative to sulphide accumulation.

The mineralized zone comprises heavily disseminated, semi-massive to massive sulphides interlayered with dark green to greenish black chloritic tuff, and locally siliceous tuff and tuffaceous sedimentary rocks, as well as discordant, stringer-type mineralization (Figures 7a to e). Locally, the sulphide zone features blue-grey (galena-rich) and brown (sphalerite-rich) laminae alternating with pyrite-, chlorite- or silica-rich layers (Figure 7d). Sulphide minerals in the stratabound lens, in order of decreasing abundance, are: pyrite, sphalerite, and galena. Appreciable Cu mineralization only occurs in conjunction with pyrrhotite and chlorite on the footwall side of the deposit (north side) in what is interpreted to represent the discordant feeder system (Figure 7e). All of the volcanic rocks interleaved with the sulphide horizons are affected by moderate to strong chloritic alteration (Figures 7b, c). Locally the host rocks appear to be agglomeratic but this is probably an effect of intense hydrothermal alteration localized along zones of weakness leaving lens-shaped "fragments" of less-altered rock. The upper contact of the sulphide zone is quite sharp, suggesting either an abrupt cessation of sulphide deposition or, more likely, erosion and burial of the deposit by volcano-sedimentary debris. Upper and lower contacts of individual sulphide-rich layers are most frequently sharp but a few are gradual, suggesting episodic burial and subsequent re-establishment of the sulphide-generating system. Alternatively, these observations may be interpreted as sub-sea-floor replacement of permeable volcanic layers.

Geologic reserves and grades have not been reported for this deposit as a whole, i.e., since the latest drill program (Lutes 1996). Assay data for this deposit ( $n = 699$ ) were captured digitally for the purpose of carrying out grade and tonnage calculations using the Geostat software package. Although the grade and tonnage calculations are not yet complete, this database was helpful in assessing metal-zonation trends throughout the deposit, and in calculating the overall metal ratio of the deposit. According to the compiled assay data, Taylor Brook has a Cu/Pb/Zn ratio of 0.1/1/2 (Figure 8a) and is in keeping with ratios reported for other Bathurst Mining Camp deposits (Franklin *et al.* 1981). Analysis of these data suggest that the stratabound part of the Taylor Brook deposit displays metal zoning, i.e., Zn+Pb-rich tops and Cu-rich bases and stringers, which is typical for volcanogenic massive sulphide (VMS) deposits (Lydon 1985; Ohmoto 1996). Metal zonation, while not ubiquitous, is apparent to some degree in most drill intersections. Zonation occurs on the scale of individual sulphide-rich beds and on the scale of total deposit thickness. For example, in drill hole TBD95-5, which is one of the thickest sulphide intersections, there are four distinct sulphide horizons, all of which display metal zoning. The uppermost of these horizons has the highest Zn+Pb values, and the Pb+Zn values increase toward the top of any one horizon. The same trends are evident in drill hole CM78-2 in the eastern part of the deposit and in hole TBD96-17 (Figure 8b, c), which intersects mineralization at depth where feeder zone mineralization is best developed. Pyrrhotite-chalcopyrite-chlorite stringer mineralization is best developed in the footwall of the western end of the deposit (drill holes TBD95-16, TBD96-17, -19, -25, -26 on Figures 4 and 5). This pyrrhotite-chalcopyrite zone is down dip from the thickest accumulation of sulphides (drill holes TBD95-5, -8, and -15 in Figures 4 and 5).

Unlike many of the major deposits in the Bathurst Mining Camp, i.e., those of the Brunswick Belt, no genetically related Algoma-type iron formation has been identified at this deposit. Other VMS deposits

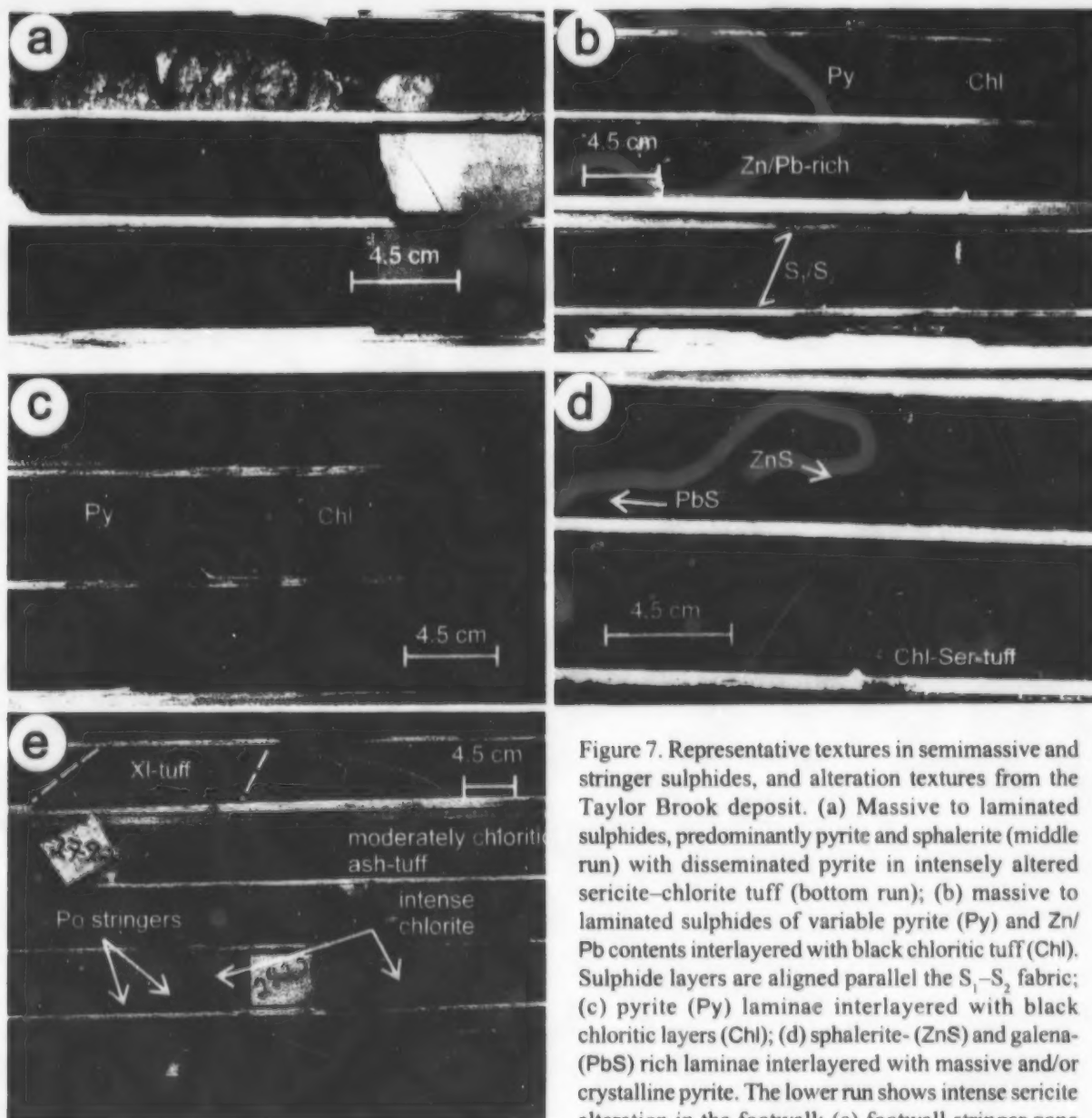


Figure 7. Representative textures in semimassive and stringer sulphides, and alteration textures from the Taylor Brook deposit. (a) Massive to laminated sulphides, predominantly pyrite and sphalerite (middle run) with disseminated pyrite in intensely altered sericite-chlorite tuff (bottom run); (b) massive to laminated sulphides of variable pyrite (Py) and Zn/Pb contents interlayered with black chloritic tuff (Chl). Sulphide layers are aligned parallel the  $S_1$ - $S_2$  fabric; (c) pyrite (Py) laminae interlayered with black chloritic layers (Chl); (d) sphalerite- (ZnS) and galena- (PbS) rich laminae interlayered with massive and/or crystalline pyrite. The lower run shows intense sericite alteration in the footwall; (e) footwall stringer zone showing intense, pervasive black chlorite alteration and discordant brown pyrrhotite (Po) stringers. Diameters of all drill core shown in these photos are the same.

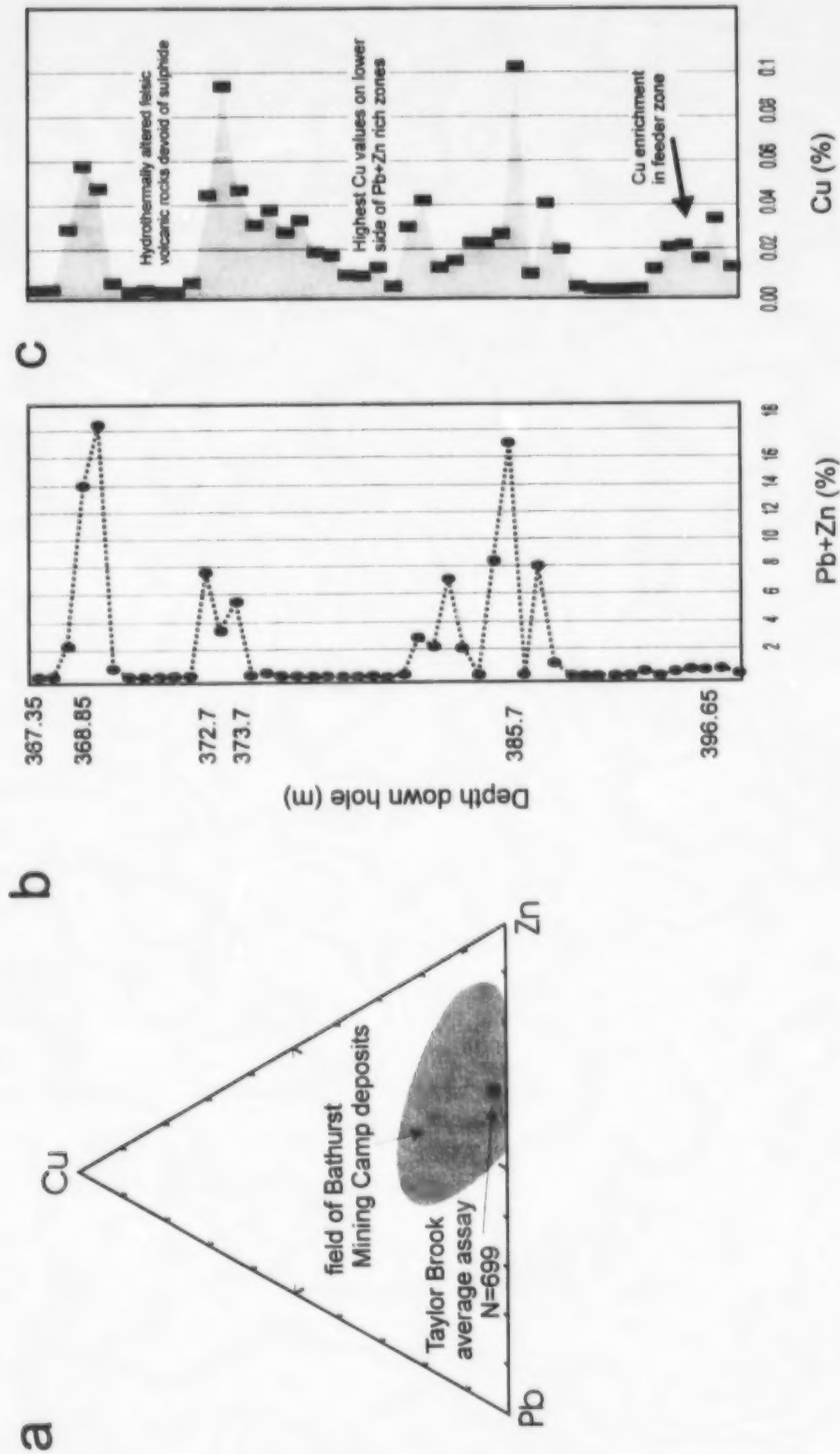


Figure 8. Metal trends in the Taylor Brook deposit. (a) Pb-Cu-Zn ternary diagram with average value for the Taylor Brook deposit. Data compiled from 699 assays reported in Lutes (1996), Miller (1993), Gummer (1978) and Burton (1978). The field of Bathurst Mining Camp deposits is approximated from Lydon (1985). (b) and (c) Metal zonation through the Taylor Brook deposit along diamond-drill hole TBD96-17. The Y axis in both (b) and (c) corresponds to hole depth in metres down the hole. Data used to compile this figure are from Lutes (1996) and represent assay intervals (0.5 and 1 m in length) through the sulphide lens.

Table 2. Lithogeochemical Data from the Taylor Brook Deposit

Drill Hole No.	TBD-95-12	TBD-95-12	TBD-95-12	TBD-95-12	TBD-95-16	TBD-95-16	TBD-95-16	TBD-95-16	TBD-95-16
Depth down hole	23.7 m	44.8 m	99.4 m	132.9 m	15.5 m	87.47 m	199.3 m	243.2 m	260 m
Rock Type	tuffaceous siltstone	ash tuff	coarse fragmental tuff	crystal tuff	aphyric rhyolite tuff	siltstone	crystal tuff	chloritic tuff	chloritic tuff
Hanging wall (HW), Footwall (FW)	HW	HW	HW	FW	HW	HW	HW	HW	HW
SiO <sub>2</sub>	69.17	79.54	63.56	54.21	72.35	64.18	69.09	51.65	50.23
TiO <sub>2</sub>	0.53	0.31	0.63	0.88	0.25	0.46	0.66	0.69	0.94
Al <sub>2</sub> O <sub>3</sub>	11.60	9.89	16.51	18.18	12.67	15.86	13.38	17.26	20.73
Fe <sub>2</sub> O <sub>3</sub> (total)	6.94	1.77	5.49	8.75	1.82	4.83	4.06	6.30	8.60
MnO	0.28	0.04	0.10	0.08	0.02	0.05	0.08	0.10	0.12
MgO	2.45	0.80	1.92	5.41	0.97	2.84	0.75	2.51	3.24
CaO	1.18	0.43	0.72	0.75	0.06	0.57	1.99	0.80	1.05
Na <sub>2</sub> O	0.00	2.93	5.00	3.55	0.03	0.65	5.41	3.63	3.84
K <sub>2</sub> O	3.51	1.90	2.81	3.67	9.70	6.24	1.31	3.66	4.07
P <sub>2</sub> O <sub>5</sub>	0.40	0.08	0.16	0.19	0.03	0.12	0.15	0.17	0.19
Total oxides	96.06	97.69	96.90	95.67	97.90	95.80	96.88	96.77	93.01
Al <sub>2</sub> O <sub>3</sub> (fresh)/Al <sub>2</sub> O <sub>3</sub> (altered)	1.09	1.28	0.77	0.70	1.00	0.80	0.95	0.73	0.61
Ba	591	682	897	978	1208	983	802	542	10316
Co	29	2	7	10	0	5	8	5	5
Cr	50	12	14	30	6	17	23	14	12
Ga	17.4	12.4	21.7	27.6	16	20	15.5	27.5	29.7
Nb	15	11	21	23	17	20	16	22	25
Ni	23	2	9	8	0	8	7	4	9
Pb	173	8	166	97	14	32	42	2	16
Rb	157	64	106	113	163	270	65	208	207
Sr	40	55	69	57	40	38	116	79	107
Th	11.73	10.09	18.36	17	29.2	20.45	12.24	16.53	21.69
U	1.47	0	8.65	2.06	1.74	0	0	0	3
V	77	38	49	109	16	29	70	55	83
Y	28	31	43	49	48	55	41	52	59
Zn	79	37	92	97	33	56	59	85	121
Zr	139	177	281	315	274	317	237	313	357
La	43	51	43	67	70	78	47	38	104
Ce	94	55	101	111	101	118	96	104	141
Nd	47	24	49	55	47	72	56	65	59

Notes: Oxides reported in wt.%, all other data reported in ppm. Chemical analysis performed at University of Ottawa via XRF.

<sup>1</sup> Average Flat Landing Brook (Langton and McCutcheon 1993)

<sup>2</sup> Average Flat Landing Brook (Langton and McDonald 1995)

<sup>3</sup> Average Flat Landing Brook (Wilson 1993b)

hosted by the Flat Landing Brook Formation, such as the Stratmat deposits, are also devoid of iron formation (Wilson 1993b; Hamilton 1992). However, Lutes (1996) has recognized lenses or fragments of magnetite, up to 3 cm in diameter and containing crystals less than 0.5 mm in diameter, in the hanging wall of the sulphide lens in two drill cores (TB96-17, -25). The magnetite is best developed in drill hole TB96-17 (Figure 6d) where it occurs as irregular (deformed?) patches within ash and lapilli tuffs and is distributed intermittently over a core length of approximately 17 m. Interestingly, the lower contact of the magnetite is some 20 m above the massive sulphide lens.

## LITHOGEOCHEMISTRY

Samples were collected from representative rock types in order to compare and contrast them with similar rocks elsewhere in the camp, and to characterize the relative degrees of hydrothermal alteration. Fourteen samples were collected from drill core: three from hanging-wall tuffaceous sedimentary rocks, three from

(Table 2 continued)

Drill Hole No.	TBD-95-16	TBD-95-16	TBD-95-16	TBD-95-8	TBD-95-8	FLB Avg <sup>1</sup>	FLB Avg <sup>2</sup>	FLB Avg <sup>3</sup>
Depth down hole	270.6 m	297.2 m	317.9 m	39.3 m	66.1 m			
Rock Type	feldspar-phyrlic rhyolite	chloritic tuff	crystal tuff (FW)	crystal-lithic tuff	chloritic tuff	Brunswick- Heath Steele n=49	Southeast of Heath Steele n=9	South of Heath Steele n=3
Hanging wall (HW), Footwall (FW)	FW	FW	FW	HW	FW			
SiO <sub>2</sub>	75.76	68.48	66.82	60.69	49.77	74.10	72.30	77.60
TiO <sub>2</sub>	0.43	0.67	0.69	0.72	0.88	0.34	0.45	0.25
Al <sub>2</sub> O <sub>3</sub>	11.11	13.75	14.58	18.33	18.21	12.38	12.92	12.98
Fe <sub>2</sub> O <sub>3</sub> (total)	5.70	5.74	5.57	5.67	11.07	3.90	4.99	1.87
MnO	0.03	0.05	0.08	0.09	0.10	0.06	0.05	0.04
MgO	1.22	2.64	1.93	2.43	7.90	1.07	1.17	0.69
CaO	0.16	0.44	1.15	0.42	0.69	0.45	1.06	0.20
Na <sub>2</sub> O	0.00	3.32	4.56	2.82	1.62	2.40	2.83	4.21
K <sub>2</sub> O	2.89	2.07	3.38	4.64	3.47	4.18	4.07	2.18
P <sub>2</sub> O <sub>5</sub>	0.11	0.15	0.15	0.19	0.19	0.09	0.11	0.03
Total oxides	97.41	97.31	98.91	96.00	93.90	98.97	99.95	100.05
Al <sub>2</sub> O <sub>3</sub> (fresh)/Al <sub>2</sub> O <sub>3</sub> (altered)	1.14	0.92	0.87	0.69	0.70	1.02	0.98	0.98
Ba	646	396	617	967	1333	799	825	354
Co	2	6	10	5	17	2	2	1
Cr	12	23	24	13	27	10	13	13
Ga	16.6	19.6	19.2	22.5	28	16	13	11
Nb	16	19	19	23	22	17	45.3	18
Ni	8	5	8	4	8	3	4	3
Pb	22	14	44	10	477	12	3	
Rb	111	80	88	212	142	127	90	79
Sr	14	40	85	44	60	71	117	52
Th	12.39	12.21	12.46	19.12	15.09	16	16.5	18.9
U	0	0	0	0	0	3.9	4.3	
V	34	76	83	53	112	23	21	8
Y	36	34	42	55	46	59	73	56
Zn	24	127	73	164	216	96	71	
Zr	201	239	251	316	309	299	411	271
La	32	44	58	45	58	50.7	66.2	56.7
Ce	58	102	59	81	118	99.5	134	107.9
Nd	16	47	35	53	53	47.1	60.3	49.7

hanging-wall tuff, five from footwall tuff, one each from footwall and hanging-wall rhyolite, and one from coarse volcanoclastic rock in the hanging wall. These data, along with average Flat Landing Brook compositions from other parts of the camp, are listed in Table 2, and locations are shown on the geological cross-section (Figure 5). Samples were agate-milled at XRAL Assay Laboratories and analyzed at the University of Ottawa by X-ray fluorescence spectrometry. Geological Surveys Branch standards submitted with this data set returned values that were within 4% of those previously determined. Sulphides were not sampled as part of this study. However, sulphides from Taylor Brook and other deposits in the Bathurst Mining Camp were sampled as part of an M.Sc. thesis project (McClenaghan, in preparation).

Samples collected for petrochemical discrimination are compared to average unaltered Flat Landing Brook data as reported by Langton and McDonald (1995), Langton and McCutcheon (1993), and Wilson (1993b). Immobile high-field-strength elements (Lentz and Goodfellow 1992; Lentz 1996a, b) are used for the purpose of protolith discrimination.

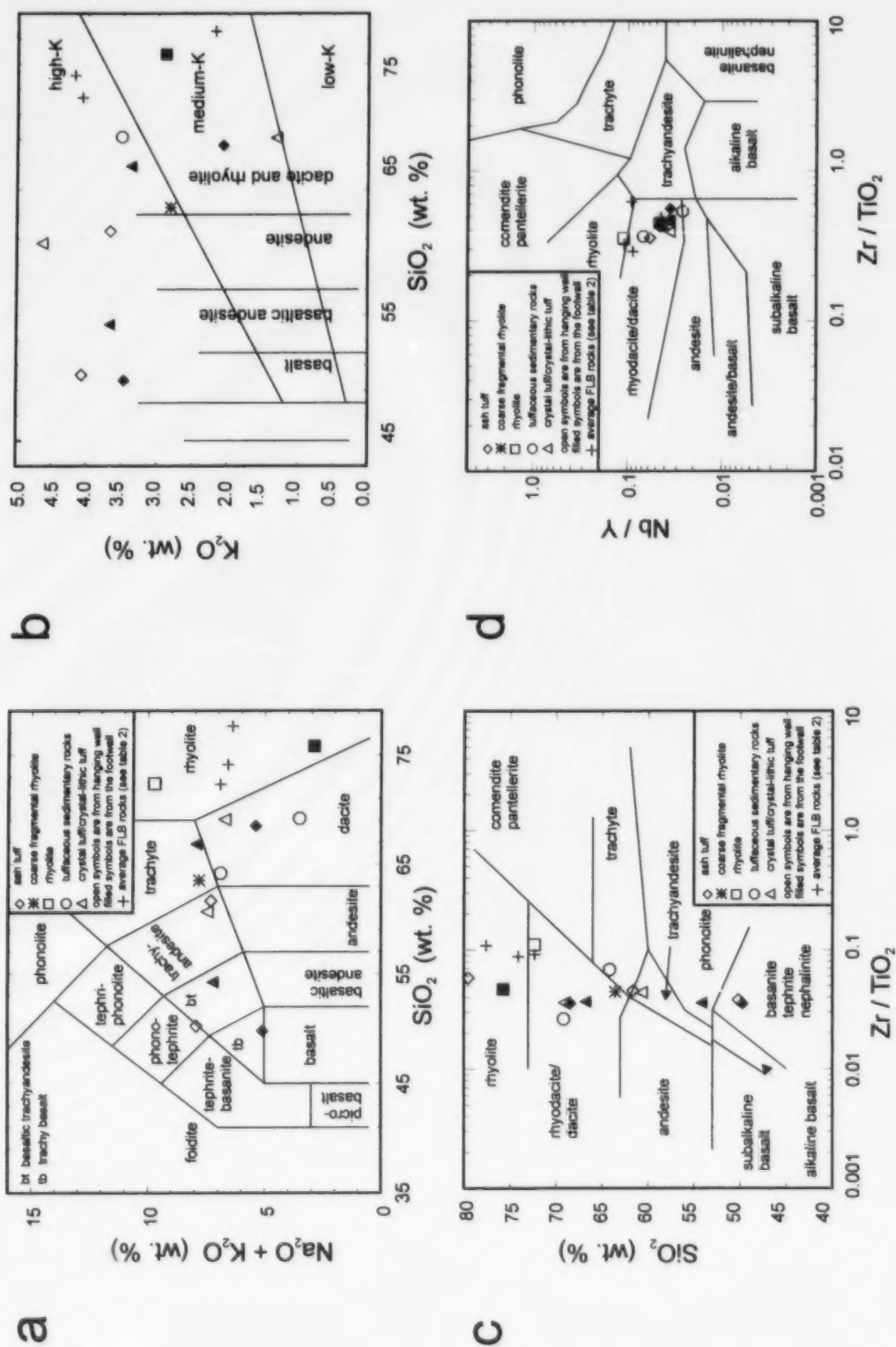


Figure 9. Major-element geochemistry of Flat Landing Brook (FLB) volcanic and volcano-sedimentary rocks from the Taylor Brook deposit. (a)  $\text{Na}_2\text{O} + \text{K}_2\text{O}$  versus  $\text{SiO}_2$  modified from LeMaitre *et al.* (1989). (b)  $\text{K}_2\text{O}$  versus  $\text{SiO}_2$  modified from LeMaitre *et al.* (1989); symbols as in (a); (c)  $\text{SiO}_2$  versus  $\text{Zr}/\text{TiO}_2$  diagram of Winchester and Floyd (1976). (d)  $\text{Nb}/\text{Y}$  versus  $\text{Zr}/\text{TiO}_2$  diagram of Winchester and Floyd, (1976). In all diagrams, + symbols correspond to the three Flat Landing Brook averages listed in Table 2.

### **Major-element chemistry**

Felsic volcanic rocks from the Taylor Brook deposit have highly variable alkali and  $\text{SiO}_2$  chemistry compared to average Flat Landing Brook compositions (Table 2 and Figures 9a–d). The lower values of  $(\text{Na}_2\text{O} + \text{K}_2\text{O})$  and  $\text{K}_2\text{O}$  (<5 and 3 wt.%, respectively) reported for Bathurst Mining Camp felsic volcanic rocks in Lentz (1996a) tend to be coincident with zones of hydrothermal alteration. Interestingly, most of the footwall samples and some of the hanging-wall samples collected from Taylor Brook have similar  $(\text{Na}_2\text{O} + \text{K}_2\text{O})$  and  $\text{K}_2\text{O}$  values. Effects of hydrothermal alteration are also suggested by the wide range in  $\text{SiO}_2$  values relative to the immobile  $\text{Zr}/\text{TiO}_2$  ratio (Figure 9c). A closer examination of major-element trends with respect to vertical distance from the ore horizon is discussed in the section on alteration.

The variance in major-element chemistry outlined above, along with petrographic evidence (extensive chlorite and sericite development), suggests that most of the Taylor Brook samples have been affected to varying degrees by hydrothermal alteration processes. In order to quantify the relative mass-addition or mass-loss due to alteration, geochemical data have been normalized to  $\text{Al}_2\text{O}_3$  (cf. Lentz 1996a, b and references therein). The correction factor employs the ratio of  $\text{Al}_2\text{O}_{3(\text{unaltered})}/\text{Al}_2\text{O}_{3(\text{altered})}$  in order to determine mass change relative to the  $\text{Al}_2\text{O}_3$  of the unaltered protolith. Because the validity of the correction factor is related to the compositional range for the normalizing element in unaltered protolith, the Taylor Brook data have been compared with regional averages (Langton and McCutcheon 1993; Langton and MacDonald 1995; Wilson 1993b). In the Taylor Brook data set, the least-altered hanging-wall rhyolite has an  $\text{Al}_2\text{O}_3 = 12.67$  wt. % that is consistent with the  $\text{Al}_2\text{O}_3 = 12.68$  wt. % value determined from average Flat Landing Brook data (Table 2).

Correction factors for the Taylor Brook samples, based on an  $\text{Al}_2\text{O}_{3(\text{fresh})}$  value of 12.68 wt. % for the unaltered protolith range between 0.61–1.28 (Table 2). This scatter in  $\text{Al}_2\text{O}_3$  values is consistent with mass loss ( $\text{Al}_2\text{O}_3$  alteration factor >1.0) or mass gain ( $\text{Al}_2\text{O}_3$  alteration factor <1.0) expected in hydrothermally altered rocks. Most of the samples below and immediately above the exhalite horizon have correction factors <1.0 and indicate mass addition, probably due to formation of hydrothermal chlorite and silica precipitation. Samples from higher stratigraphic levels have correction factors of 1 or slightly greater, suggesting mass loss.

### **Trace-element and high-field-strength-element chemistry**

Felsic volcanic rocks in the Taylor Brook area fall within the rhyodacite/dacite and rhyolite fields on the  $\text{Zr}/\text{TiO}_2$  versus  $\text{Nb}/\text{Y}$  discrimination diagram (Figure 9d) like Flat Landing Brook rocks from elsewhere in the Bathurst Mining Camp, e.g., the Heath Steele area (Wilson 1993b) and the Brunswick belt (Lentz and Goodfellow 1992). However, footwall rocks cluster in the rhyodacite/dacite field close to the andesite boundary, whereas hanging-wall rocks overlap the footwall samples and extend into the rhyolite field. Interestingly, the footwall samples occupy that part of the diagram in which rocks from the Nepisiguit Falls Formation typically plot, although overlap between this and the Flat Landing Brook Formation is recognized (Lentz and Goodfellow 1992; Lentz 1996b).

A spider diagram for mantle-normalized trace-element data from Taylor Brook felsic volcanic rocks is presented in Figure 10a. As expected for samples collected in proximity to a massive sulphide deposit, these rocks contain elevated Pb and Zn, presumably in the form of sulphides, relative to unaltered rocks. Anomalous Ba in some samples is probably related to fixing of Ba from sea water. Some samples have elevated V and Ti values, probably resulting from mass loss of other components through hydrothermal processes (see section on alteration). Most rocks are depleted in U, La, Nd, Y, Nb, Sr and Ce relative to unaltered Flat Landing Brook rocks. Low Sr values are attributed to hydrothermal destruction of K-

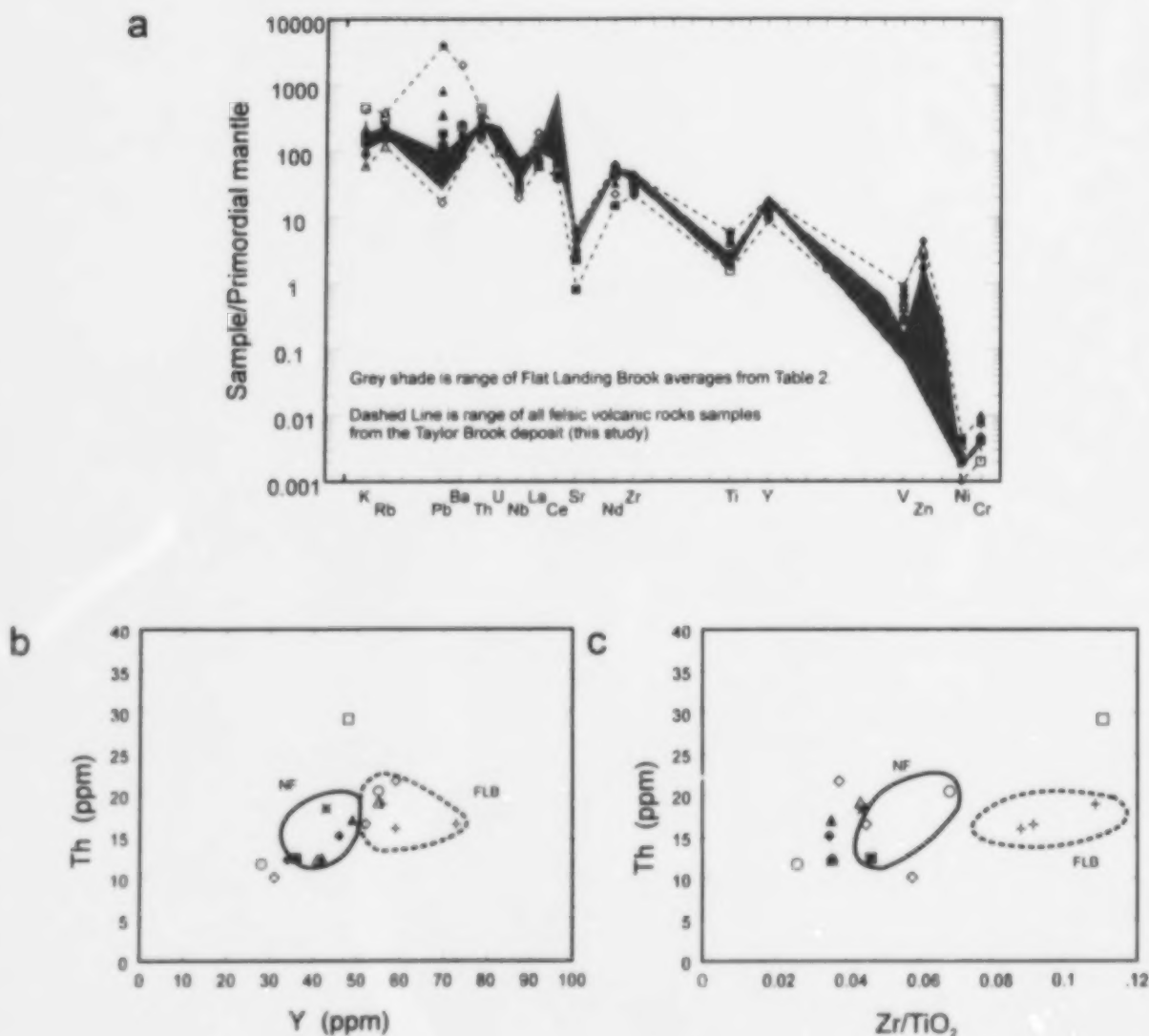
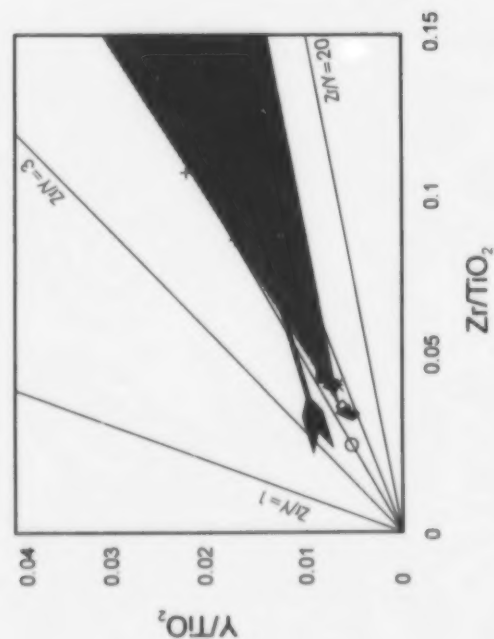


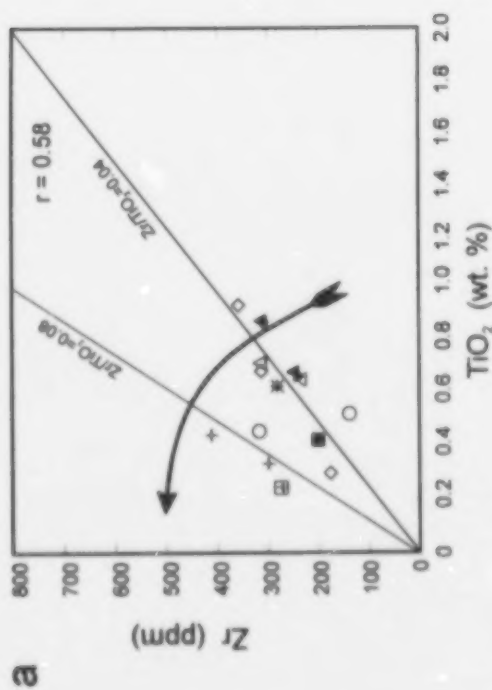
Figure 10. Trace-element chemistry from the Taylor Brook deposit. (a) Mantle-normalized spider diagram. Normalization factors are from Taylor and McLennan (1985). (b) Y versus Th and (c) Zr/TiO<sub>2</sub> versus Th diagrams comparing Taylor Brook felsic volcanic rocks with the average Flat Landing Brook (FLB) and Nepisiguit Falls (NF) rocks reported in Lentz (1996b). Symbols as in Figure 9a.

feldspar in which Sr substitutes for K (Faure 1991). The content of other trace elements in the Taylor Brook samples resembles that of average Flat Landing Brook rocks (Table 2).

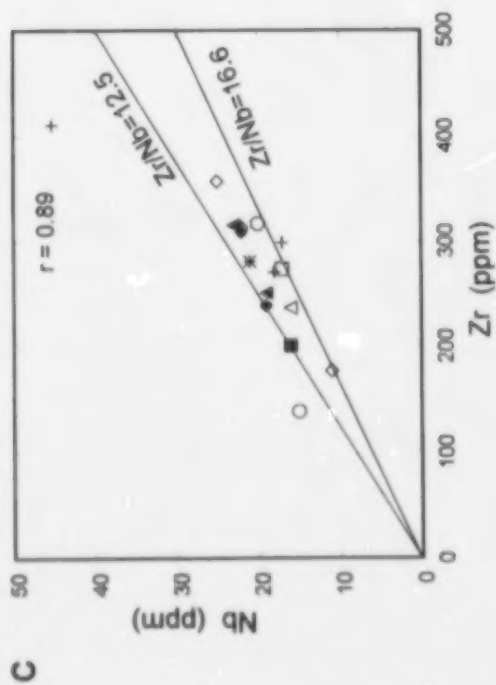
Lentz (1996b) demonstrated that Flat Landing Brook rocks have a higher content of Y, Th, Zr, Nb and Ta than the Nepisiguit Falls Formation. These elements are considered to be immobile even under extreme hydrothermal conditions (Lentz 1996a) and, therefore, are considered to be good petrochemical discriminants. When data from the Taylor Brook deposit are plotted on Th versus Zr/TiO<sub>2</sub> and Th versus Y diagrams, it is evident that most of the Taylor Brook rocks coincide with the Nepisiguit Falls field and



b



a



c

Figure 11. Trace-element geochemistry of Taylor Brook rocks. (a) Zr versus  $\text{TiO}_2$  variation diagram. Heavy black arrow indicates normal fractionation trend where Zr increases and  $\text{TiO}_2$  decreases in the melt. (b)  $\text{Zr}/\text{TiO}_2$  versus  $\text{Y}/\text{TiO}_2$  discrimination diagram; (c) Nb versus Zr discrimination diagram.  $r$  = Pearson correlation coefficient from Appendix A. Symbols as in Figure 9a.

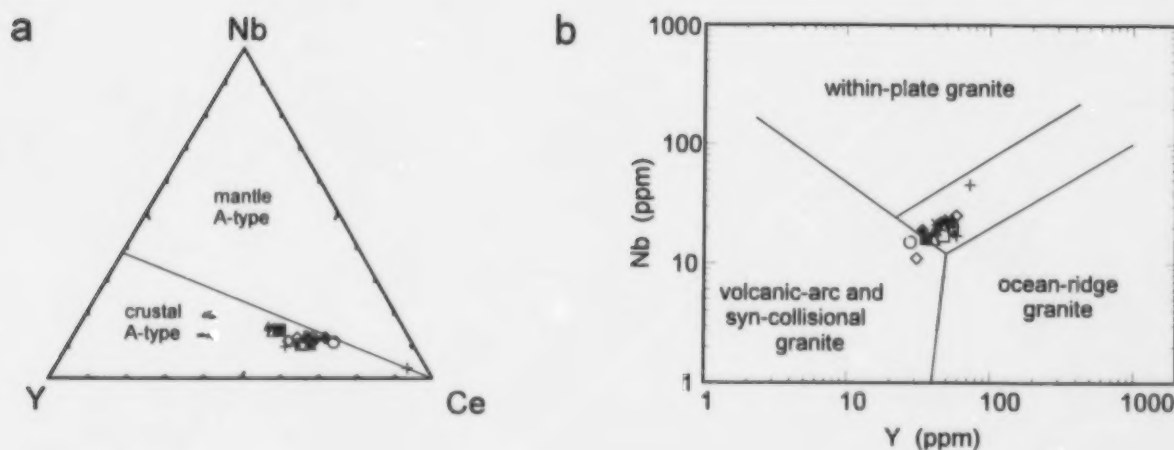


Figure 12. Tectonic discrimination diagrams for Taylor Brook data. (a) Y–Nb–Ce magmatic provenance diagram of Eby (1992), and (b) Nb versus Y diagram (field boundaries from Pearce *et al.* 1984). Symbols are the same as in Figure 9a.

not the Flat Landing Brook field. This is due to lower Y and  $Zr/TiO_2$  contents in the Taylor Brook rocks relative to the averages presented in Lentz (1996b). This might be explained by a statistically limited sample set, or else these elements may have been mobile in the Taylor Brook hydrothermal system (Figures 10b, c).

A Zr versus  $TiO_2$  diagram (Figure 11a) shows that most of the Taylor Brook data plot along a line corresponding to a  $Zr/TiO_2$  ratio of approximately 0.04, with a Pearson Correlation Coefficient value of 0.58 (Appendix A), whereas average Flat Landing Brook data (Table 2) exhibit  $Zr/TiO_2 > 0.08$ . The deviation in the  $Zr/TiO_2$  ratio to lower values relative to the average Flat Landing Brook rocks is not likely an effect of alteration-induced mass loss, as inferred from the  $Al_2O_3$  alteration factors (discussed above), because mass loss would tend to increase this ratio. Rather, the variation probably reflects local variation in the source magma or the various stability controls of Zr- and  $TiO_2$ -rich phases. However, these data have not been subjected to detailed mass-balance calculations, and significant overlap is also noted by Lentz (1996b).

The Zr/Nb values for the Taylor Brook samples range between 12.5 and 16.5 (Figure 11c) and have typically low Zr (150–350 ppm) values and has a Pearson Correlation Coefficient value of 0.89 (see appendix). These are consistent with high-K rhyolite and a subalkaline affinity as suggested for other felsic volcanic rocks in the Bathurst Mining Camp (Lentz 1996b and references therein).

On the  $Zr/TiO_2$  versus  $Y/TiO_2$  diagram (Figure 11b), volcanic rocks from the Taylor Brook deposit occur within the same field as those of Flat Landing Brook rocks from elsewhere in the Bathurst Mining Camp (cf. Rogers and van Staal 1996). The Taylor Brook samples cluster along a line with a Zr/Y value of approximately 5.5, which is more restricted than the range of Zr/Y for the Flat Landing Brook Formation, i.e., 4.8 to 10 (Figure 11b). The tight clustering of the Taylor Brook data is probably due to the relatively small stratigraphic interval sampled.

The Y–Nb–Ce tectonic discrimination diagram (Figure 12a) of Eby (1992) shows that the Taylor Brook samples plot in the crustally derived A-type granite field, which is characterized by generally low Nb, and is consistent with the average Flat Landing Brook rocks reported in Lentz (1996b). These values are slightly higher than those reported for Nepisiguit Falls rocks (Lentz 1996b). On the Y versus Nb tectonic discrimination diagram of Pearce *et al.* (1984), Taylor Brook rocks plot mostly in the within-plate granite field (Figure 12b), which is consistent with Flat Landing Brook rocks elsewhere in the Bathurst Mining Camp (Lentz and Goodfellow 1992), and with the A-type granite classification (Figure 12a).

Three samples of tuffaceous sedimentary rocks are plotted on the Nb/Y versus Zr/TiO<sub>2</sub> discrimination diagram (Figure 6a). These samples are also plotted on most of the discrimination diagrams discussed above, and closely follow the trends for the felsic volcanic rocks, suggesting that they are derived from a similar rhyodacite/dacite source.

### **Footwall alteration**

The footwall rocks of the Taylor Brook deposit, like those of most proximal volcanogenic massive sulphide systems, are strongly affected by hydrothermal alteration that is contemporaneous with and genetically related to the mineralizing event. At depth (>250 m vertical depth) in the western part of the deposit, a zone of intensely chloritic felsic tuffs lies below the stratabound sulphides. In places, the chloritic zone is cut by veins of pyrrhotite, pyrite and, locally, chalcopyrite, which may be greater than 2 cm in width (Figure 7e). The sulphide–chlorite assemblage is best developed in cores from drill holes TBD95-16, -17, etc.

Trace-element systematics (see above) suggest that the protoliths of the footwall rocks were probably felsic volcanic rocks similar to those in the hanging wall. However, only 50 m of footwall stratigraphy was sampled as compared to 300 m of hanging-wall stratigraphy so conclusions based on these data should be treated with caution. Selected major-element oxide and major-element ratios are plotted with respect to the distance up-hole or down-hole from the exhalite horizon (0 m in Figure 13) indicate that the hanging wall and footwall are quite different in terms of their major-element chemistry. It has been shown that Fe<sub>2</sub>O<sub>3(tot)</sub>, MgO, MnO, and CaO increase in footwall rocks with increasing proximity to the exhalite horizon in volcanogenic massive sulphide deposits of the Bathurst Mining Camp (Lentz 1996b). Major-element trends from the Taylor Brook deposit are consistent with those of other Bathurst deposits, in particular, the increases in Fe<sub>2</sub>O<sub>3(tot)</sub> and MgO that are directly attributable to the formation of hydrothermal chlorite as described in Franklin *et al.* (1981), Lentz (1996a), and others. Na<sub>2</sub>O decreases slightly toward the sulphide horizon, possibly reflecting the development of hydrothermal albite as suggested by Lentz (1996b). Major-element ratios, such as MgO/CaO, Mg/K, Fe/K, Fe/Mg, and Mg/K which reflect the processes of chlorite formation and feldspar destruction, generally increase erratically (except K/Na which decreases) toward the exhalite horizon from the footwall side. These ratios represent a guide to exploration, in that they increase with increasing intensity of alteration, and those with the highest values are interpreted to represent a subsurface conduit through which hydrothermal fluids passed en route to the vent site.

Selected trace-element data, i.e., Nb, Pb, Co, Y, Zr, and Zn, are also plotted against distance from the exhalite horizon for this deposit. As expected, Zn and Pb concentrations are high at the exhalite horizon and erratic in proximal hanging-wall rocks, whereas they reach maximum values in the immediate footwall (Figure 13). These trends indicate leaching of these elements by hydrothermal fluids in the footwall, rapid metal dumping at the exhalite horizon, and gradual decline in metal deposition in stratigraphically higher rocks as the system wanes.

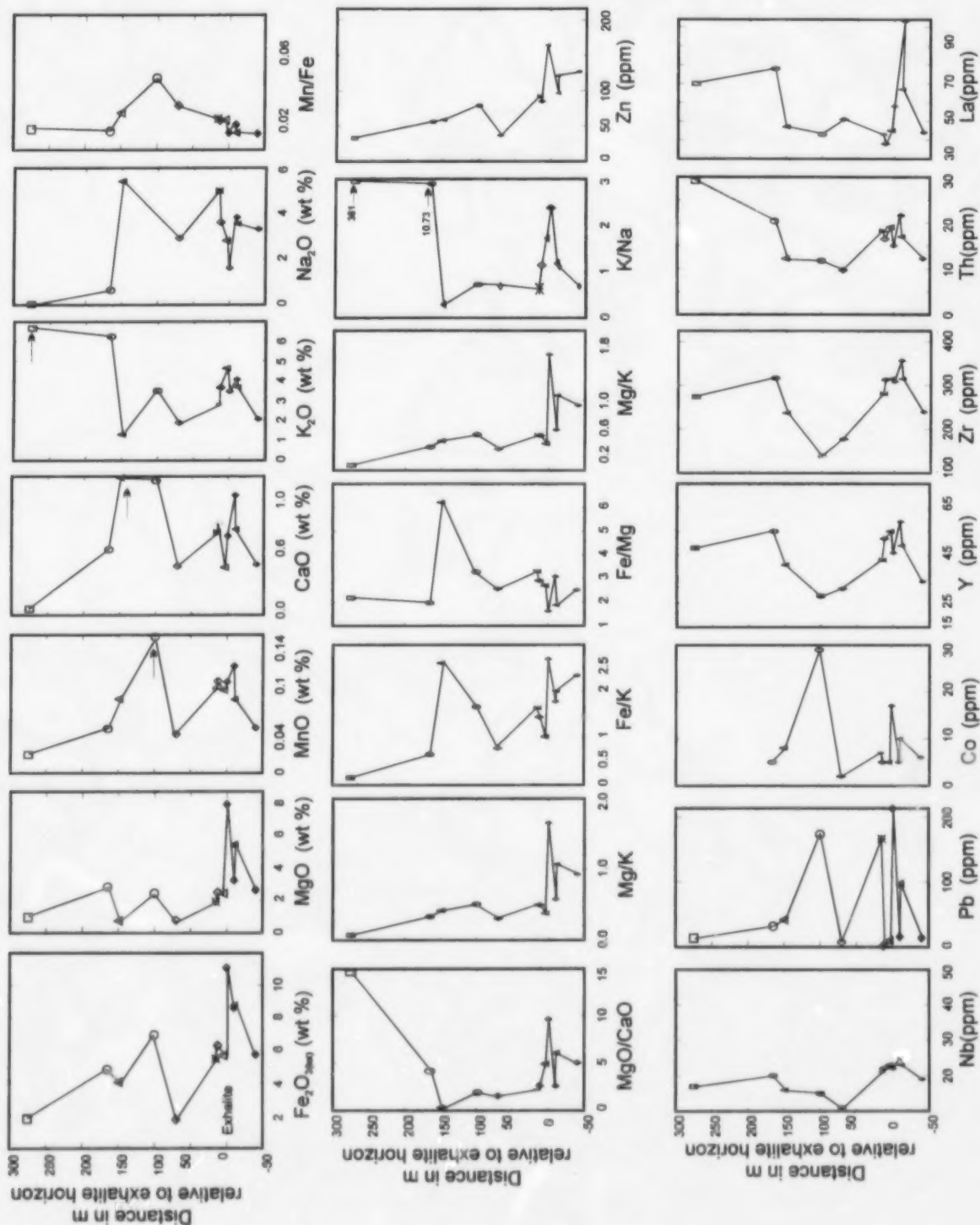


Figure 13. Selected major-element, major-element-ratio, and trace-element data plotted with respect to the exhalite horizon (0 m) in drill hole TBD96-17. Some of the data points are projected from adjacent holes (see Figure 5). Symbols as in Figure 9a.

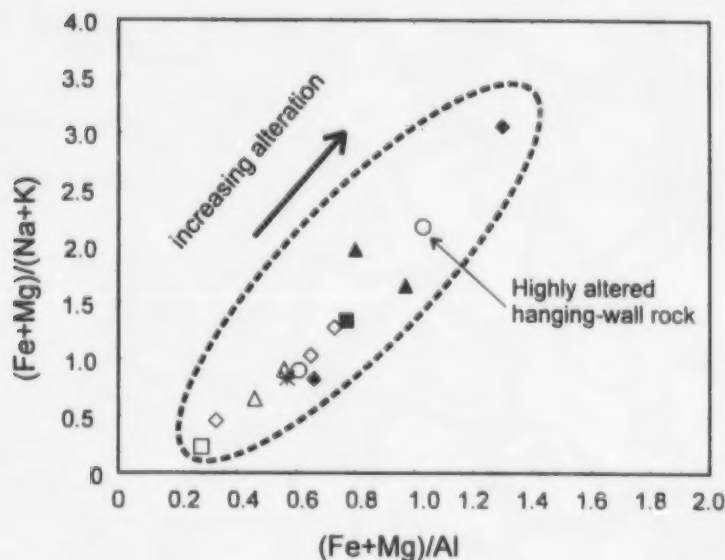


Figure 14.  $(\text{Fe}+\text{Mg})/(\text{Na}+\text{K})$  versus  $(\text{Fe}+\text{Mg})/\text{Al}$  alteration index diagram for Flat Landing Brook volcanic and volcano-sedimentary rocks from the Taylor Brook deposit. Symbols as in Figure 9a.

### ***Hanging-wall alteration***

Hanging-wall alteration, although not ubiquitous, is well developed in some horizons. Variability in the localization of hanging-wall alteration is probably a function of original permeability of the rock units. Those horizons with increased permeability were more favourable for fluid migration and, consequently, for the development of hydrothermal alteration.

Miller (1993) reported  $\text{Na}_2\text{O}$  depletion trends in outcrop samples in the vicinity of the deposit. Values of 0.5 wt. %  $\text{Na}_2\text{O}$  are noted immediately adjacent to the sulphide body, as compared to background values of >2 wt. %. This is presumably a result of feldspar-destructive hydrothermal alteration processes (cf. Franklin *et al.* 1981). According to Miller (1993), the gradient of  $\text{Na}_2\text{O}$  depletion is quite steep in both the footwall and hanging-wall sides of the deposit. The symmetric nature of the low  $\text{Na}_2\text{O}$  envelope would suggest that hydrothermal fluids penetrated hanging-wall rocks after the deposit was buried. A second, broader zone of  $\text{Na}_2\text{O}$  depletion occurs 450 m to the southwest of the deposit. This may indicate a second zone of hydrothermal alteration or a structural repetition of the deposit stratigraphy. However, because of limited outcrop and the lack of a definitive marker horizon, any conclusion drawn from these data should be treated with caution.

There is some evidence for the development of a hydrothermal alteration assemblage in the hanging-wall rocks at the Taylor Brook deposit. As is evident from the major- and trace-element chemistry presented in Figure 13, there are local increases in  $\text{Fe}_2\text{O}_3$ ,  $\text{MgO}$ ,  $\text{MnO}$  and  $\text{CaO}$  in the hanging wall, which suggest that hydrothermal fluid flow occurred after the main sulphide-generating episode.

On an  $(\text{Fe}+\text{Mg})/(\text{Na}+\text{K})$  versus  $(\text{Fe}+\text{Mg})/\text{Al}$  diagram (Figure 14), which has been shown to be an effective index of hydrothermal alteration in the Bathurst Mining Camp (Lentz 1996a, b), it is clear that many of

the footwall rocks are strongly altered, whereas alteration in the hanging wall is less intense. Lutes (1996) reported the presence of silica-carbonate-talc alteration that is locally developed in the hanging wall of the deposit. Previously, talc has only been reported in one other deposit in the Bathurst Mining Camp, namely the Stratmat Boundary-Heath Steele N5 deposit (Hamilton 1992). Many of the samples from below or immediately above the sulphide zone have low  $\text{SiO}_2$  values (49–65 wt. %). Compared to  $\text{SiO}_2$  ranges of 72.4–75.8 and 72.3–77.6 wt. % for the least-altered Taylor Brook samples and average Flat Landing Brook rocks, respectively, there is an apparent  $\text{SiO}_2$  loss of 10 and 35% for some samples. This  $\text{SiO}_2$  loss is attributed to the increased solubility of  $\text{SiO}_2$  at high temperatures associated with syngenetic feldspar-destructive hydrothermal alteration (Holland and Malinin 1979).

## DISCUSSION

The presence of stratabound pyrite-sphalerite-galena-rich sulphide lenses locally overlying zones of pyrrhotite-chalcopyrite-chlorite (stringer zone) mineralization suggests that the Taylor Brook deposit represents a proximal autochthonous setting (Jambor 1979). The relative position of the stratabound and stringer mineralization, together with internal Zn+Pb/Cu zonation, demonstrate that the sequence hosting the deposit youngs to the south and southwest. The consistent spatial relationship and relative position of the stringer- and stratabound-type mineralization of individual layers is consistent with a deposit comprising several layers/horizons of massive sulphides rather than repetition of a single sulphide layer due to folding.

The best-developed stringer mineralization is overlain by relatively thin accumulations of stratabound sulphides, whereas thicker accumulations of stratabound sulphides occur structurally up-dip and are underlain by less intensely altered rocks. It is possible that the fluids were focused along fault-controlled conduits and, upon reaching the near-surface, spread out into confined permeable layers. Alternatively, hydrothermal fluids vented on the sea floor and flowed down slope to accumulate in a small depression in a manner akin to the Type II brine model of Sato (1972). The brine pool model is supported by the apparent lack of brecciated sulphides, which would be expected if down-slope, mass-wasting of a sulphide mound were the mechanism of sulphide deposition (Lydon 1985). However, the original thickness and spatial relationship between the stratabound- and stringer-sulphide zones may have been greatly affected during deformation such that structural transposition may obscure original relationships.

It is not known whether the magnetite intersected by drill hole TBD96-17 (20 m above sulphide mineralization) represents a tectonically fragmented oxide iron-formation facies of the Taylor Brook deposit or direct precipitation of magnetite in a permeable layer. Its presence is problematic as it occurs within a sequence where sulphide is stable, i.e., reducing conditions are dominant above and below the interval of magnetite clasts. In order for magnetite to be stable, paleo-environmental conditions must have been oxidizing; this may be accomplished in several ways: (1) Upward growth of the volcanic pile may bring it into contact with the oxygenated part of the water column, i.e. into the magnetite stability field. Later collapse of the pile will drop the volcanic sequence back into deeper water where sulphides once again are stable (reducing conditions). (2) The magnetite occurs in rocks that probably had a high primary permeability, and would serve as good conduits for the flow of hydrothermal fluids. If these fluids were oxidized, magnetite may have precipitated at some time syn- to post-deposition of the volcanic sequence. (3) The magnetite may have formed in a shallower part of the basin dominated by oxidizing conditions. Erosion and down-slope movement may have introduced these fragments into the Taylor Brook stratigraphy as detritus via down-slope movement but the diffuse and irregular nature of the magnetite boundaries does not favour this hypothesis.

If we assume that the magnetite mineralization discussed above was introduced from shallower depths and is not directly related to the Taylor Brook exhalite horizon, the absence of related iron formation could be explained in a couple of ways. Firstly, paleo-environmental conditions at the site of deposition were not conducive to the formation of iron-oxide facies, i.e., reducing conditions dominated the water column. Second, burial of the deposit by volcanic material was rapid enough to keep it from reacting with oxygenated sea water, thereby precluding the formation of an oxidized iron formation. The latter seems to be more likely, as sedimentary horizons that typically denote periods of quiescence do not occur immediately above or below the sulphide horizon. Sedimentary units do occur at stratigraphically higher horizons suggesting a slowing of the rate of volcanic deposition and/or the occurrence of short-lived hiatuses in volcanic activity. The presence of locally, moderately well-developed, sericitic alteration in hanging-wall rocks suggests that the hydrothermal system was active for some time after deposition of the volcanic material that smothered the system.

## CONCLUSIONS

1. The Taylor Brook deposit is a proximal autochthonous volcanogenic massive sulphide deposit and is characterized by stratabound Zn+Pb sulphide mineralization and spatially associated discordant Cu-pyrrhotite stringer-type mineralization.
2. The deposit is hosted by ash and lapilli tuff of the Flat Landing Brook Formation, and has a sheet-like morphology with a strike of 600 m or more and a down-dip thickness of 600 m. The mineralized zone comprises one to four sulphide-rich horizons. The zone is <4 m thick on average but may be up to 65 m in thickness.
3. The deposit is right-way-up, as determined from metal zonation trends, dips approximately 45° and youngs to the south or southeast.
4. There is no appreciable difference in the petrochemistry of footwall and hanging-wall felsic volcanic rocks at the Taylor Brook deposit, with the exception of variations attributable to hydrothermal alteration.
5. The intimate interlayering of sulphide-bearing horizons and barren felsic volcanic rocks suggests that volcano-sedimentary deposition was concurrent with sulphide deposition. It is possible that some of the stratabound mineralization was deposited in the subsurface.
6. Hydrothermal alteration in the footwall is characterized by extensive development of chlorite whereas, hanging-wall rocks feature local weak to moderate sericite and chlorite alteration.
7. The Taylor Brook deposit occurs in the Flat Landing Brook Formation, and the rock types are similar to those associated with past producing deposits of the Stratmat belt. However, the stratigraphic positions of the Stratmat and Taylor Brook deposits within the Flat Landing Brook Formation as well as their stratigraphic positions relative to one another are unknown.

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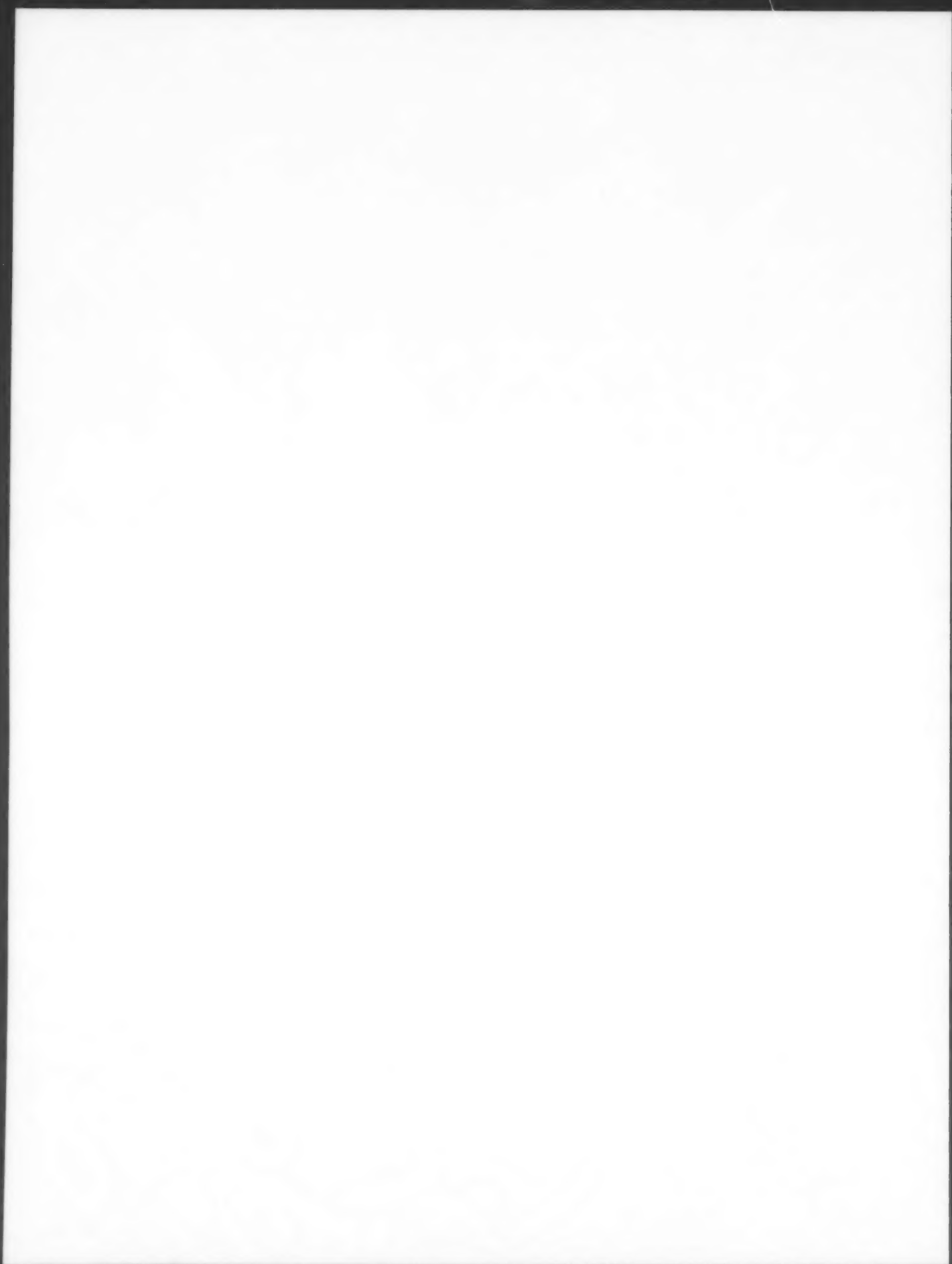
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Appendix A. Pearson Correlation Coefficient [r] Values for Taylor Brook Data Presented in Table 2.

	SiO <sub>2</sub>	TiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub> (T)	MnO	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	Ba	Co	Cr	Ga	Nb	NI	Pb	Nb	Sr	Ti	Th	U	V	Y	Zn	Zr	La	Ce	Nd
SiO <sub>2</sub>	1																												
TiO <sub>2</sub>	-0.86	1																											
Al <sub>2</sub> O <sub>3</sub>	-0.94	0.82	1																										
Fe <sub>2</sub> O <sub>3</sub> (T)	-0.84	0.85	0.67	1																									
MnO	-0.25	0.29	0.10	0.43	1																								
MgO	-0.81	0.68	0.62	0.87	0.20	1																							
CaO	-0.21	0.43	0.13	0.20	0.48	-0.02	1																						
Na <sub>2</sub> O	-0.25	0.52	0.36	0.06	-0.08	-0.05	0.56	1																					
K <sub>2</sub> O	-0.06	-0.35	0.11	-0.22	-0.19	-0.02	-0.48	-0.55	1																				
P <sub>2</sub> O <sub>5</sub>	-0.32	0.42	0.16	0.56	0.96	0.32	0.45	-0.08	-0.30	1																			
Ba	-0.51	0.44	0.54	0.33	0.13	0.14	0.16	0.15	0.09	0.07	1																		
Co	-0.25	0.30	0.00	0.53	0.88	0.43	0.45	-0.16	-0.23	0.90	-0.12	1																	
Cr	-0.15	0.27	-0.10	0.45	0.78	0.36	0.48	-0.11	-0.32	0.85	-0.22	0.94	1																
Ga	-0.94	0.84	0.93	0.82	0.19	0.74	0.07	0.24	0.04	0.28	0.49	0.13	0.04	1															
Nb	-0.90	0.79	0.97	0.87	0.06	0.59	0.02	0.29	0.17	0.15	0.46	-0.03	-0.11	0.92	1														
NI	-0.14	0.21	-0.05	0.44	0.86	0.19	0.44	-0.20	-0.25	0.89	0.07	0.87	0.83	0.07	-0.04	1													
Pb	-0.48	0.36	0.23	0.65	0.35	0.77	0.10	-0.13	-0.12	0.37	-0.09	0.62	0.45	0.34	0.17	0.37	1												
Nb	-0.38	0.05	0.49	0.16	0.15	0.18	-0.23	-0.39	0.80	0.12	0.33	-0.05	-0.18	0.42	0.48	0.04	-0.09	1											
Sr	-0.38	0.52	0.41	0.14	0.14	0.00	0.79	0.79	-0.31	0.08	0.47	0.01	-0.02	0.30	0.27	-0.03	-0.02	-0.14	1										
Ti	-0.88	1.00	0.83	0.85	0.29	0.68	0.42	0.52	-0.35	0.42	0.44	0.30	0.27	0.85	0.79	0.21	0.36	0.06	0.52	1									
Th	-0.30	-0.08	0.42	-0.10	-0.23	0.03	-0.36	-0.23	0.86	-0.34	0.36	-0.38	-0.49	0.28	0.45	-0.34	-0.13	0.59	-0.03	0.16	0.12	0.32	1						
U	-0.20	0.11	0.26	0.07	0.19	-0.03	0.01	0.29	0.03	0.09	0.23	0.02	-0.08	0.19	0.26	0.19	0.16	0.07	0.16	0.12	0.32	1							
Y	-0.68	0.05	0.48	0.82	0.42	0.74	0.48	0.37	-0.44	0.54	0.20	0.59	0.62	0.59	0.43	0.39	0.56	-0.26	0.39	0.84	-0.35	1							
Zn	-0.77	0.75	0.68	0.74	0.25	0.76	0.05	0.15	0.49	-0.21	0.50	-0.38	-0.45	0.68	0.81	-0.34	-0.10	0.70	0.30	0.44	0.71	0.09	0.01	1					
Zr	-0.78	0.58	0.81	0.41	-0.27	0.47	-0.07	0.28	-0.14	0.37	0.20	0.35	0.22	0.68	0.65	0.08	0.62	0.16	0.14	0.75	0.01	0.00	0.66	0.31	1				
La	-0.50	0.27	0.50	0.19	-0.07	0.26	0.06	0.00	0.45	-0.13	0.77	-0.34	-0.42	0.79	0.89	-0.38	0.05	0.55	0.33	0.59	0.63	0.17	0.19	0.95	0.48	1			
Ce	-0.75	0.53	0.70	0.52	0.21	0.53	0.16	0.05	0.27	0.21	0.56	-0.14	-0.17	0.39	0.42	-0.06	-0.04	0.43	0.33	0.27	0.57	0.11	0.15	0.61	0.10	0.57	1		
Nd	-0.64	0.44	0.68	0.31	0.21	0.37	0.31	0.18	0.29	0.22	0.23	0.13	0.09	0.58	0.63	0.06	0.10	0.62	0.36	0.44	0.46	0.10	0.20	0.68	0.37	0.67	0.42	0.82	1

Calculated according to Rollinson (1983)



# LITHOGEOCHEMISTRY, PETROGRAPHY AND GEOCHRONOLOGY OF ORDOVICIAN ROCKS IN THE BIG BALD MOUNTAIN AREA (NTS 21 O/1), BATHURST MINING CAMP, NEW BRUNSWICK ‡

R.A. Wilson<sup>1</sup>, L.R. Fyffe<sup>2</sup>, V. McNicoll<sup>3</sup> and N. Wodicka<sup>1</sup>

<sup>1</sup>New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch, P.O. Box 50, Bathurst, New Brunswick, CANADA E2A 3Z1 (e-mail: rawilson@gov.nb.ca)

<sup>2</sup>New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch, P.O. Box 6000, Fredericton, New Brunswick, CANADA E3B 5H1 (e-mail: lrfyffe@gov.nb.ca)

<sup>3</sup>Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, CANADA K1A 0E8 (e-mail: vmcnicol@nrcan.gc.ca; nwodicka@nrcan.gc.ca)

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The Big Bald Mountain area is underlain by volcanic and sedimentary rocks of the Middle Ordovician Tetagouche and Sheephouse Brook groups, and by sedimentary rocks of the Cambro-Ordovician Miramichi Group. The Tetagouche Group, to the north of a major dextral strike-slip fault traversing the northern part of the study area, comprises the Nepisiguit Falls Formation (quartz-feldspar crystal tuff, and sedimentary rocks of the Little Falls Member), Flat Landing Brook Formation (feldspar-phyric rhyolite, and tholeiitic basalt and minor crystal tuff of the Forty Mile Brook Member) and Little River Formation (mainly alkalic basalt). The Sheephouse Brook Group, which occurs predominantly to the south of the above fault, includes the Clearwater Stream Formation (plagioclase-phyric dacite tuff), Sevogle River Formation (feldspar-phyric rhyolite and minor sedimentary rocks), and Slacks Lake Formation (alkalic and tholeiitic basalts, trachyandesites, comendites, graphitic shale and chert, and cherty ironstone).

Petrographic and geochemical diversity in volcanic rocks from the Sheephouse Brook and Tetagouche groups support tectonostratigraphic models that invoke emplacement in separate basins from separate magma sources. Although felsic volcanic rocks from all units have similar profiles on trace- and rare-earth-element spidergrams, they vary markedly in relative rare-earth-element abundance. The Clearwater Stream and Sevogle River formations have comparable abundances of most trace elements, including rare-earth elements; however, their contents of large-ion lithophile elements, high-field-strength elements, and rare-earth elements are higher than in the Flat Landing Brook Formation, and much higher than in the Nepisiguit Falls Formation. Felsic volcanic rocks in the Sheephouse Brook Group are also distinguished by higher Zr/Y, Nb/Y, Zr/Hf, Nb/Ta, Ba/Sr and Rb/Sr compared to Tetagouche felsic rocks. Felsic subvolcanic and plutonic rocks in the survey area chemically resemble the volcanic rocks, with minor variations, and evidently share a similar petrogenetic history. For example, the Squirrel Falls Porphyry and Clearwater Lake Porphyry are very similar to the Clearwater Stream Formation and Sevogle River Formation, respectively, and evidently represent their subvolcanic equivalents.

Mafic volcanic rocks in the Tetagouche Group include tholeiitic basalts of the Forty Mile Brook Member (Flat Landing Brook Formation) and overlying alkalic basalts of the Brunswick Mines Member (Little River Formation). The Forty Mile Brook tholeiites have mid-ocean ridge basalt affinities (flat rare-earth-element profiles (average La/Yb = 1.7), low Nb/Y and Zr, and high Cr,

‡ Contribution to the EXTECH-II program (New Brunswick Geological Surveys Branch ordinary budget).

Ni and V), whereas the Brunswick Mines Member is typical of within-plate alkalic basalts, with sloping rare-earth-element profiles (average  $\text{La/Yb} = 8.6$ ), and high  $\text{Nb/Y} (> 0.7)$ , and  $\text{TiO}_2 (> 2.5\%)$ , although Cr is relatively high compared to Brunswick Mines basalts elsewhere in the Bathurst Mining Camp. Mafic volcanic rocks in the Slacks Lake Formation (Sheephouse Brook Group) include sub-alkalic basalts, alkalic basalts and trachyandesites. Sub-alkalic basalts are typical of continental tholeiites, with lower Cr, Ni and Y, steeper rare-earth-element profiles (average  $\text{La/Yb} = 5.3$ ), and higher  $\text{Nb/Y}$  compared to the Forty Mile Brook tholeiites. Alkalic basalts in the Slacks Lake Formation have higher contents of rare-earth elements, large-ion lithophile and high-field-strength elements, and lower Cr compared to the Brunswick Mines alkalic basalts. However, rare-earth-element profiles have similarly steep slopes (average  $\text{La/Yb} = 9.3$ ). Trachyandesites and comendites in the Slacks Lake Formation presumably constitute a fractionation sequence with the alkalic basalts, and are very enriched in high-field-strength elements, rare-earth elements, Ga and Th.

A new U-Pb date ( $465 \pm 2/-1$  Ma) for crystal tuffs interbedded with Forty Mile Brook tholeiitic basalts in the Flat Landing Brook Formation (Tetagouche Group) is consistent with previously acquired ages for this unit. A U-Pb age of  $466 \pm 2$  Ma obtained on the Sevogle River Formation (Sheephouse Brook Group) enables a time correlation to be made with Flat Landing Brook rhyolites. The Clearwater Stream Formation (Sheephouse Brook Group) has been dated at  $478 \pm 3/-1$  Ma, considerably older than the Nepisiguit Falls Formation (Tetagouche Group), which appears to occupy the same stratigraphic position. Therefore, the Sevogle River Formation may have been deposited unconformably on the Clearwater Stream Formation. A new date obtained from the Stony Brook Porphyry ( $471 \pm 2$  Ma) indicates that it is much older than the chemically similar subvolcanic intrusive rocks of the Clearwater Lake Porphyry, which intrudes the Sevogle River Formation. Although more chemically evolved, the Stony Brook Porphyry is believed to be contemporaneous with the Squirrel Falls Porphyry.

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Le secteur du mont Big Bald repose sur des roches volcaniques et sédimentaires des groupes de l'Ordovicien moyen de Tetagouche et du ruisseau Sheephouse ainsi que sur des roches sédimentaires du groupe cambro-ordovicien de Miramichi. Le groupe de Tetagouche, au nord d'une faille à décrochement dextre importante traversant la partie septentrionale du secteur d'étude, englobe la Formation de Nepisiguit Falls (tuf cristallin quartzo-feldspathique et roches sédimentaires du membre Little Falls), la Formation de Flat Landing Brook (rhyolite feldspatho-porphyrique, basalte tholéitique et faible quantité de tuf cristallin du membre Forty Mile Brook) et la Formation de Little River (principalement du basalte alcalin). Le groupe du ruisseau Sheephouse, qui est principalement présent au sud de la faille susmentionnée, comprend la Formation de Clearwater Stream (tuf dacitique plagioclase-porphyrique), la Formation de Sevogle River (rhyolite feldspatho-porphyrique et faible quantité de roches sédimentaires) et la Formation de Slacks Lake (basaltes alcalins et tholéitiques, trachyandésites, comendites, chert et schiste graphitique, et grès ferrugineux cherteux).

La diversité pétrographique et géochimique des roches volcaniques des groupes du ruisseau Sheephouse et de Tetagouche supportent des modèles tectonostratigraphiques invoquant une intrusion dans des bassins séparés de sources séparées de magma. Même si les roches volcanofelsiques de toutes les unités présentent des profils semblables sur les diagrammes radiocentriques des éléments traces et éléments des terres rares, l'abondance relative des éléments des terres rares varie de façon marquée. Les formations de Clearwater Stream et de Sevogle River

présentent des abondances comparables de la plupart des éléments traces, y compris les éléments des terres rares; elles renferment cependant plus d'éléments lithophiles à gros ions, d'éléments à champ de rayonnement de forte intensité et d'éléments des terres rares que la Formation de Flat Landing Brook, et beaucoup plus que la Formation de Nepisiguit Falls. Les roches volcanofelsiques du groupe du ruisseau Sheephouse se distinguent en outre par des teneurs supérieures en Zr/Y, Nb/Y, Zr/Hf, Nb/Ta, Ba/Sr et Rb/Sr à celles des roches felsiques de Tetagouche. Les roches subvolcanofelsiques et plutoniques du secteur d'étude ressemblent chimiquement aux roches volcaniques, avec de petites variations, et elles partagent manifestement un passé pétrogénétique similaire. La formation porphyrique de Squirrel Falls et celle de Clearwater Lake sont par exemple très semblables à la Formation de Clearwater Stream et à celle de Sevogle River, respectivement, et elles représentent manifestement leurs équivalents subvolcaniques.

Les roches volcanomafiques du groupe de Tetagouche comprennent des basaltes tholéiitiques du membre Forty Mile Brook (Formation de Flat Landing Brook) et des basaltes alcalins sus-jacents du membre Brunswick Mines (Formation de Little River). Les tholéiites de Forty Mile Brook possèdent des affinités avec les basaltes de la ride océanique (profils plats des éléments des terres rares (présence moyenne de  $\text{La/Yb} = 1,7$ ), faible teneur de Nb/Y et de Zr, et teneur élevée de Cr, de Ni et de V), tandis que le membre Brunswick Mines est caractéristique des basaltes alcalins intra-plaque, avec des profils inclinés d'éléments des terres rares (présence moyenne de  $\text{La/Yb} = 8,6$ ) et une teneur élevée en Nb/Y ( $> 0,7$ ) et  $\text{TiO}_2$  ( $> 2,5\%$ ), même si la teneur en Cr est relativement élevée comparativement aux basaltes de Brunswick Mines ailleurs dans le Camp minier de Bathurst. Les roches volcanomafiques de la Formation de Slacks Lake (groupe du ruisseau Sheephouse) comprennent des basaltes subalcalins, des basaltes alcalins et des trachyandésites. Les basaltes subalcalins sont typiques des tholéiites continentaux, avec des teneurs moindres en Cr, Ni et Y, des profils plus accentués d'éléments des terres rares (présence moyenne de  $\text{La/Yb} = 5,3$ ) et des teneurs plus élevées de Nb/Y que les tholéiites de Forty Mile Brook. Les basaltes alcalins de la Formation de Slacks Lake renferment plus d'éléments des terres rares, d'éléments lithophiles à gros ions et d'éléments à champ de rayonnement de forte intensité ainsi que moins de Cr que les basaltes alcalins de Brunswick Mines. Les profils d'éléments des terres rares présentent toutefois des inclinaisons tout aussi fortes (présence moyenne de  $\text{La/Yb} = 9,3$ ). On présume que les trachyandésites et les comendites de la Formation de Slacks Lake constituent une séquence de fractionnement avec les basaltes alcalins et ils sont énormément enrichis d'éléments à champ de rayonnement de forte intensité, d'éléments des terres rares, de Ga et de Th.

La nouvelle datation au U-Pb ( $465 \pm 2/-1$  Ma) des tufs cristallins interstratifiés avec les basaltes tholéiitiques de Forty Mile Brook dans la Formation de Flat Landing Brook (groupe de Tetagouche) est conforme aux âges déjà obtenus par rapport à cette unité. La datation au U-Pb de  $466 \pm 2$  Ma obtenue en ce qui concerne la Formation de Sevogle River (groupe du ruisseau Sheephouse) permet d'effectuer une corrélation temporelle avec les rhyolites de Flat Landing Brook. La Formation de Clearwater Stream (groupe du ruisseau Sheephouse) a été située à  $478 \pm 3/-1$  Ma, ce qui est infiniment plus âgé que la Formation de Nepisiguit Falls (groupe de Tetagouche), qui semble occuper la même position stratigraphique. La Formation de Sevogle River pourrait s'être déposée de façon discordante sur la Formation de Clearwater Stream. Le nouvel âge obtenu de la formation porphyrique de Stony Brook ( $471 \pm 2$  Ma) révèle que celle-ci est beaucoup plus âgée que les roches intrusives subvolcaniques chimiquement analogues de la formation porphyrique de Clearwater Lake, qui font intrusion dans la Formation de Sevogle River. Même si la formation porphyrique de Stony Brook semble chimiquement plus évoluée, on croit qu'il s'agit d'une unité contemporaine de la formation porphyrique de Squirrel Falls.

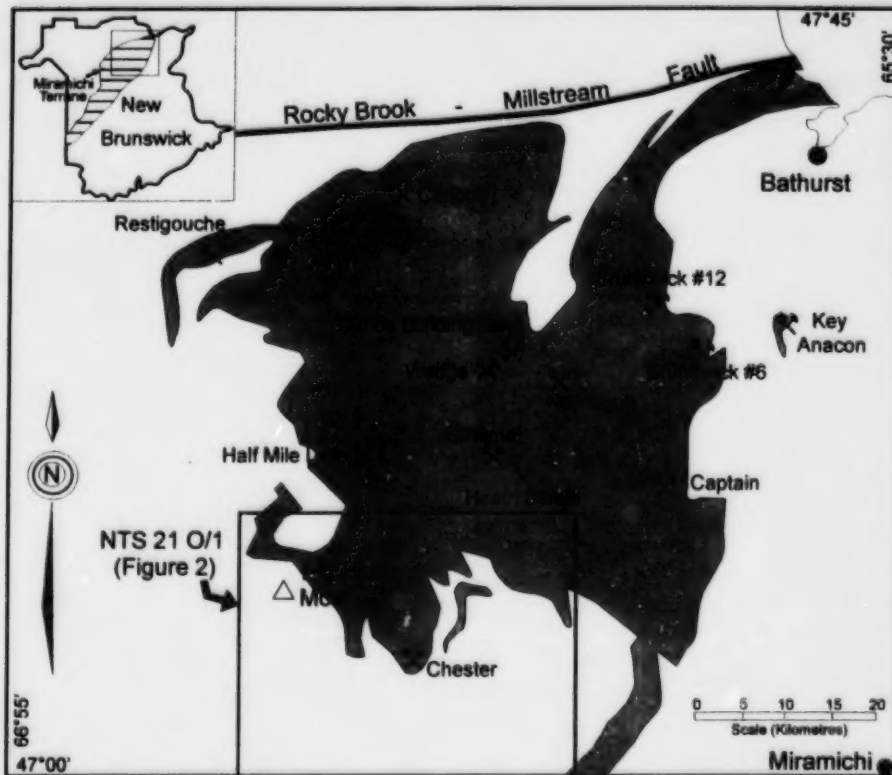


Figure 1. Location map showing study area and major sulphide deposits of the Bathurst Mining Camp. The shaded area is underlain by volcanic and sedimentary rocks of the Tetagouche, Sheephouse Brook and California Lake groups.

## INTRODUCTION

Geological mapping in the Big Bald Mountain area was carried out between 1992 and 1995 under the Canada–New Brunswick Cooperation Agreement on Mineral Development (1990–1995) and the Federal-Provincial EXTECH-II program (1994–1999). In recent years, efforts among the participants in EXTECH-II mapping programs have increasingly focused on integrating the results of all field and laboratory investigations, in order to present a holistic tectonostratigraphic picture of the Bathurst Mining Camp (Wilson *et al.* 1998). Crucial to these interpretations have been lithogeochemical and geochronological data accumulated over a period of several years (e.g., van Staal 1987; van Staal *et al.* 1991; Sullivan and van Staal 1993, 1996; Rogers and van Staal 1996; Rogers *et al.* 1997). Work to date in the Bathurst Mining Camp has shown that felsic, mafic and sedimentary rocks occur in several major thrust sheets or nappes, where they form distinct tectonostratigraphic packages. However, the rocks occupying each nappe are roughly contemporaneous (based on radiometric and fossil data), although lithological and lithogeochemical variations suggest the existence of distinct magmatic “provinces”. This paper assembles all of the published and unpublished lithogeochemical data from the Big Bald Mountain area, as well as systematic petrography and recent isotopic dates, in order to (1) compare and contrast these rocks with those in other parts of the Camp, and (2) support the interpretive model referred to above. The regional

stratigraphy and lithological descriptions of volcanic, intrusive, and sedimentary rocks in this area have previously been reported, along with summary information on mineral occurrences and private sector mineral exploration (Wilson and Fyffe 1996). The lithogeochemistry of parts of the Big Bald Mountain area has also been discussed in previous reports (Fyffe 1995a; Wilson 1995a).

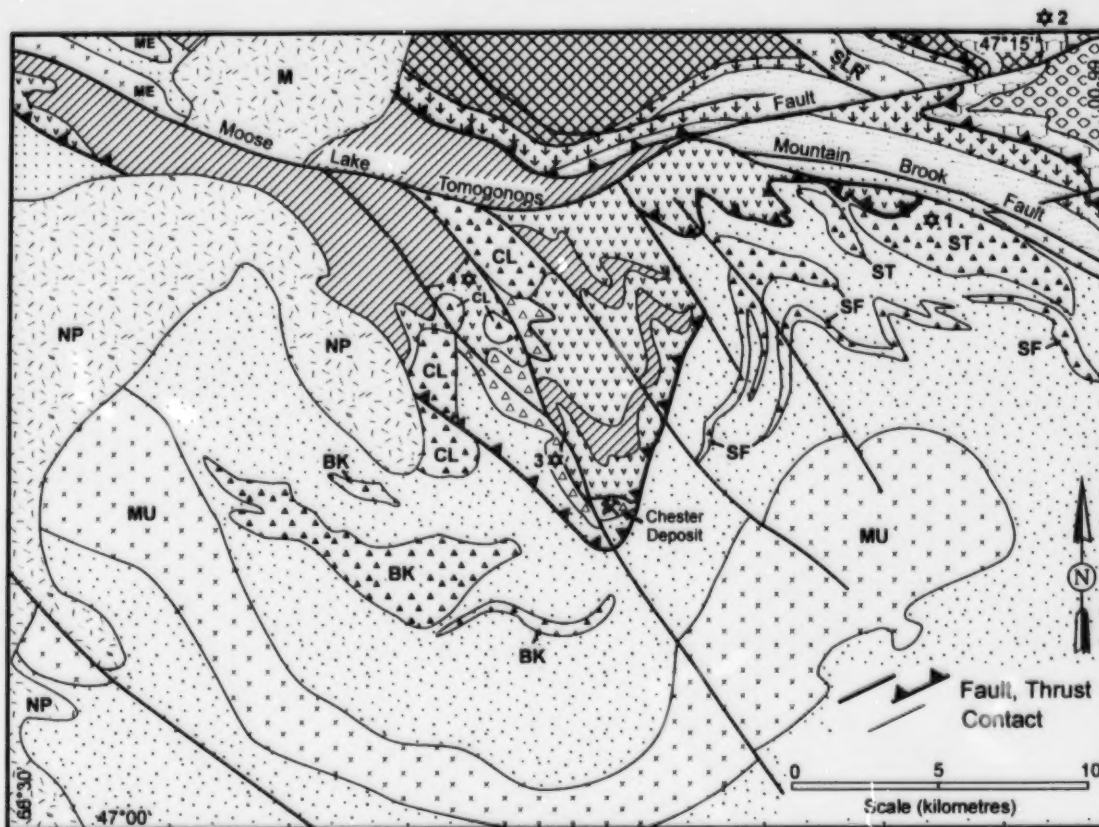
## GEOLOGICAL SETTING

The rocks of the Bathurst Mining Camp are part of the northern Miramichi Terrane (Figure 1), and have previously been separated into three groups, namely the Miramichi, Tetagouche and Fournier groups (van Staal and Fyffe 1991; van Staal *et al.* 1992). Arenigian to Caradocian bimodal volcanic rocks and interbedded sedimentary rocks of the Bathurst Mining Camp were deposited in an ensialic back-arc basin, disconformably to unconformably overlying quartzose turbidites of the Cambro-Ordovician Miramichi Group, which possibly represent the passive margin of the Avalon composite terrane. In Llandeilian to Caradocian time, the back-arc evolved into a full-fledged oceanic basin, which is represented by a dismembered ophiolite sequence and overlying pillow basalts and marine sedimentary rocks of the Fournier Group (van Staal and Fyffe 1991). During subduction-related closure of the back-arc basin (ca. 445–425 Ma), the ensialic volcano-sedimentary pile was incorporated into an accretionary complex that was thrust over the Gondwanan (Avalon) basin-margin rocks as a series of imbricate sheets or nappes. These rocks are structurally overlain by Fournier oceanic crustal rocks along a blueschist suture zone (van Staal *et al.* 1990). Volcanic rocks in the accretionary complex were probably originally deposited in at least three sub-basins that are now tectonically juxtaposed along thrust faults defining major nappe boundaries (McCutcheon *et al.* 1997). The volcanic and sedimentary rocks composing the major nappes were all formerly included in the Tetagouche Group, but are now subdivided into the California Lake, Tetagouche, and Sheephouse Brook groups (Wilson *et al.* 1998).

The Big Bald Mountain area (Figure 1) is underlain by rocks of the Miramichi, Sheephouse Brook and Tetagouche groups. The northern part of the area is transected by late-stage dextral strike-slip faults (the Moose Lake–Tomogonops and Mountain Brook faults); Tetagouche rocks are found only to the north of these faults, whereas Miramichi and Sheephouse Brook rocks occur predominantly to the south (Figure 2). The Cambro-Ordovician Miramichi Group consists of the Chain of Rocks, Knights Brook and Patrick Brook formations—a generally fining-upward sequence that has been correlated with the Gander Group of Newfoundland (van Staal and Fyffe 1991).

The Sheephouse Brook Group comprises, in ascending stratigraphic order, the Clearwater Stream, Sevogle River and Slacks Lake formations. The Clearwater Stream Formation consists of plagioclase-phyric dacitic tuffs, whereas the Sevogle River Formation comprises feldspar-phyric rhyolite. The Slacks Lake Formation, formerly considered part of the Boucher Brook Formation, consists of alkalic to tholeiitic, apparently non-pillowed, basalt; dark grey, locally graphitic shale; maroon to green chert; and domes or spines of peralkaline felsic volcanic rock (comendite). Detailed lithological descriptions of these units are given in Wilson and Fyffe (1996). The Sheephouse Brook Group is juxtaposed against the Tetagouche Group along an unnamed thrust fault in the north-central part of the Big Bald Mountain area, and along the Mountain Brook (strike-slip) Fault in the northeastern part of the survey area (Figure 2).

The Tetagouche Group occupies the core of the Bathurst Mining Camp, and consists, in ascending order, of the Nepisiguit Falls, Flat Landing Brook and Little River formations. The Nepisiguit Falls Formation in the Big Bald Mountain area comprises quartz- and feldspar-phyric pyroclastic and local effusive volcanic rocks, and sedimentary rocks. The latter include interbedded greenish grey siltstone, sandstone, feldspathic



## LEGEND

- Late Silurian-Early Devonian, medium-to coarse-grained biotite granite (NP - North Pole Stream Granite; M - Miramichi Granite)
- Ordovician, foliated, medium-grained granite (MU - Mullin Stream Lake Granite; SLR - South Little River Lake Granite; ME - Meridian Brook Granite)
- Mid-Ordovician, foliated, fine-grained felsic hypabyssal intrusive rocks; ST - Stony Brook Porphyry; BK - Barracks Brook Granite; CL - Clearwater Lake Porphyry; SF - Squirrel Falls Porphyry

### Middle Ordovician Tetagouche Group

- LITTLE RIVER FORMATION: alkalic basalt, minor felsic tuff and shale (Brunswick Mines Member)
- FLAT LANDING BROOK FORMATION: tholeiitic basalt (Forty Mile Brook Member) aphyric to feldspar-phyric rhyolite
- NEPISIGUIT FALLS FORMATION: quartz-feldspar crystal tuff; siltstone, feldspathic wacke, shale (Little Falls Member)

### Sheephouse Brook Group

- SLACKS LAKE FORMATION (alkalic and tholeiitic basalt, shale, chert, comendite)
- SEVOLE RIVER FORMATION (alkali-feldspar-phyric rhyolite)
- CLEARWATER STREAM FORMATION (plagioclase-phyric dacitic tuff)

### Cambro-Ordovician Miramichi Group

- Quartzite, quartz wacke, siltstone, shale, feldspathic wacke

wacke and local crystal tuff that are collectively assigned to the Little Falls Member, and constitute roughly 50% of the Nepisiguit Falls Formation in the survey area. Isotopic dates on the volcanic rocks range from  $469 \pm 2$  Ma (Sullivan and van Staal 1996) to  $473 +5/-3$  Ma (Rogers *et al.* 1997). The Flat Landing Brook Formation consists of greyish pink aphyric to sparsely feldspar-phyric rhyolite and local felsic hyaloclastic breccia; it has been dated at 465–466 Ma (Sullivan and van Staal 1990, 1996; Rogers *et al.* 1997). In the Big Bald Mountain area, the Flat Landing Brook Formation also includes tholeiitic basalts (Forty Mile Brook Member) containing minor interbedded rhyolite and peralkaline crystal tuff. The Little River Formation underlies the extreme northeastern part of the survey area and consists of alkalic basalt (Brunswick Mines Member), and minor peralkaline felsic volcanic rocks and dark grey shale. Elsewhere in the Bathurst Mining Camp, the age of the Little River Formation is defined by Caradocian graptolites in sedimentary rocks and a U–Pb age of  $457 \pm 1$  Ma (Sullivan and van Staal 1996) from comenditic flows interbedded with alkalic basalts.

Several suites of felsic hypabyssal and plutonic rocks intrude the stratified rocks in the survey area, particularly south of the Moose Lake–Tomogonops and Mountain Brook faults. These include Ordovician fine-grained porphyritic intrusions (Squirrel Falls Porphyry, Stony Brook Porphyry and Clearwater Lake Porphyry) that are probable subvolcanic equivalents of some of the felsic volcanic rocks, and coarser-grained, foliated Ordovician plutonic rocks (Mullin Stream Lake Granite, Meridian Brook Granite, Clarks Brook Granite, and South Little River Lake Granite). The Barracks Brook Granite has both porphyritic and equigranular phases and, therefore, may reflect emplacement at intermediate levels. Coarse-grained, non-foliated Late Silurian–Early Devonian plutons include the Miramichi Granite and North Pole Stream Granite. The reader is referred to Whalen (1993) and Whalen *et al.* (1998) for lithological and petrographic descriptions, geochemistry, geochronology and isotope characteristics of most plutonic rocks.

## PETROGRAPHY

### *Sheephouse Brook Group*

In the Clearwater Stream Formation, deformation and metamorphism have in most cases obliterated all primary features; however, subtle bedding features are locally preserved in outcrop, suggesting pyroclastic emplacement. Dacitic tuffs of the Clearwater Stream Formation typically contain from 20 to 45% subhedral plagioclase phenocrysts (0.4–3.0 mm) set in a fine-grained recrystallized matrix (35–55%) of quartz and plagioclase (0.05–3.0 mm). Calcite (0–15%) commonly occurs as an alteration product of the phenocrasts (together with up to 5% epidote) and as porphyroblasts in the matrix. Abundant muscovite (5–30%), biotite (0–25%) and chlorite (0–25%) with included titanite impart a penetrative schistosity to the rock. The biotite content varies inversely with that of chlorite. Accessory minerals include apatite, zircon, Fe–Ti oxides and pyrite. Samples of the Clearwater Stream Formation south and east of the Chester deposit (Figure 2) possess fewer (10–15%) and smaller (0.4–1.5 mm) plagioclase phenocrasts and less total biotite plus chlorite.

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Figure 2. (facing page) Simplified geological map of the Big Bald Mountain area. Numbered stars show locations of samples collected for radiometric dating: 1 = sample O/1h-677 (Stony Brook Porphyry); 2 = sample O/8a-3934 (Flat Landing Brook Formation); 3 = sample O/1b-25 (Clearwater Stream Formation); 4 = sample O/1f-110 (Sevogle River Formation).

Rhyolites of the Sevogle River Formation contain 5–30% alkali feldspar phenocrysts (0.2–2.0 mm) and 0–20% plagioclase phenocrysts (0.2–1.5 mm), set in a very fine-grained felsitic matrix (0.01–0.30 mm) composing 30–70% of the rock. The alkali feldspars display tartan twinning typical of microcline, contain exsolved perthite lamellae, and are partially replaced by patches of quartz and calcite. The plagioclase phenocrysts, which are usually less abundant than alkali feldspar, display albite twinning and are partially altered to epidote. Muscovite (5–40%) and biotite (0–10%), partially altered to chlorite and titanite, define a variably developed planar fabric in the rock. Where strain is high, the primary felsitic matrix is extensively recrystallized to a granular aggregate with a prominent schistosity, mainly defined by increased muscovite content, enveloping augened feldspar phenocrysts. Accessory minerals include apatite, monazite, zircon, Fe–Ti oxides and pyrite.

Mafic volcanic rocks of the Slacks Lake Formation have spilitic mineral assemblages; textures are typically strongly schistose, varying to mylonitic in proximity to major faults in the area. The mineral assemblage consists mainly of plagioclase (15–65%, 0.05–0.50 mm) and chlorite (0–65%),  $\pm$  calcite (0–35%)  $\pm$  epidote (0–15%)  $\pm$  titanite (0–15%)  $\pm$  actinolite (0–40%)  $\pm$  Fe–Ti oxides (0–10%, commonly magnetite porphyroblasts), rare biotite (0–5%) and quartz (0–5%). Trachyandesites are distinguished by their greater abundance of quartz (up to 20%), biotite (up to 15%), and generally higher plagioclase content (40–65%).

Intermediate to felsic volcanic rocks in the Slacks Lake Formation include olive green to reddish maroon, Mn-stained comenditic domes, and greyish green trachytic flows that are locally interbedded with mafic volcanic rocks. Comendites typically contain phenocrysts of either alkali feldspar (10–35%, 0.3–5.0 mm) or plagioclase (5–25%, 0.3–1.0 mm), plus biotite (0–20%) and/or muscovite (5–40%) in a very fine-grained, commonly turbid felsitic matrix (40–80%, 0.01–0.10 mm) containing abundant very fine-grained hematitic inclusions. Accessory minerals include zircon, titanite, epidote, riebeckite and/or green hornblende.

### ***Tetagouche Group***

Quartz–feldspar crystal tuffs of the Nepisiguit Falls Formation contain 0–20% (average 10%) subhedral to anhedral phenocrysts/phenocrasts of quartz (0.2–5.0 mm), and 5–20% (average 15%) anhedral to subhedral phenocrysts of feldspar, including alkali feldspar (0–20%, 0.3–3.5 mm) and plagioclase (0–20%, 0.2–3.0 mm). Quartz crystals are locally embayed and commonly broken; some breakage is related to deformation, but much breakage evidently occurred during eruption and emplacement. Alkali feldspars are typically cloudy and display local replacement by albite or sericite. Phenocrysts/clasts typically occur as augens within a schistose, microfelsitic matrix (typically 60–80%, 0.01–0.03 mm) characterized by tectono-metamorphic differentiated layering of felsite and phyllosilicates. In rare cases, primary pyroclastic textures are preserved in the matrix. The latter consists of muscovite (0–40%) with or without biotite (0–20%); calcite is also commonly present (0–5%). Accessory minerals include titanite, zircon, apatite, epidote, monazite, rare garnet and Fe–Ti oxides. Petrographically, the Nepisiguit Falls Formation is distinguished from the Clearwater Stream Formation by the absence of quartz and alkali feldspar, and the greater abundance of biotite, chlorite and calcite in the latter.

Rhyolites of the Flat Landing Brook Formation typically contain 0–20% anhedral to euhedral phenocrysts or porphyroclasts of plagioclase (0.1–2.0 mm) in a schistose, recrystallized microfelsitic matrix that locally preserves subtle devitrification features such as spherulitic or perlitic texture. Groundmass mineralogy

consists of feldspar (50–90%, 0.01–0.03 mm), muscovite (0–45%) ± biotite (0–15%) ± chlorite (0–10%) ± calcite (0–10%) and accessory minerals (titanite, apatite and/or Fe–Ti oxides). The main petrographic difference between the Flat Landing Brook Formation and the Sevogle River Formation is the scarcity of alkali feldspar in the former.

### ***Intrusive rocks***

The Squirrel Falls Porphyry contains between 10% and 45% plagioclase phenocrysts (0.4–3.0 mm), enveloped by a schistosity defined by the preferred orientation of muscovite (5–30%) and biotite (0–25%). Alkali feldspar phenocrysts (0.3–1.5 mm) form up to 10% of the phenocryst population in some samples. Plagioclase is partially altered to epidote and calcite; and biotite to chlorite and titanite. The fine-grained (0.2–0.5 mm) recrystallized matrix (35–60%) comprises an assemblage of quartz, plagioclase and minor alkali feldspar. Accessory minerals include garnet, allanite, monazite, zircon, Fe–Ti oxides and pyrite. Garnet porphyroblasts range up to 0.7 mm in diameter and are commonly partially altered to chlorite. Euhedral yellowish brown allanite crystals (0.3 mm) are internally zoned and rimmed by epidote.

The Clearwater Lake Porphyry contains up to 30% (typically 15–20%) anhedral to euhedral alkali feldspar (0.3–3.5 mm) in a microfelsitic matrix (30–75%, 0.02–0.05 mm) that is locally recrystallized to a coarser-grained (0.10–0.15 mm) felsite. A metamorphic differentiated layering of felsitic and phyllosilicate phases is observed in some thin sections. Locally, plagioclase phenocrysts (0.3–3.0 mm) are present in amounts ranging from 5 to 35%; quartz phenocrysts are rare. Muscovite occurs abundantly (up to 45%) in almost all thin sections, whereas biotite (up to 10% in some samples) and epidote (replacing plagioclase, up to 3%) are less common, and chlorite and calcite are rare. Common accessory minerals are zircon, apatite, titanite and Fe–Ti oxides, whereas monazite, allanite and tourmaline are rare.

The Stony Brook Porphyry consists of phenocrysts of alkali feldspar (5–35%, average 15%, 0.3–8.0 mm), plagioclase (5–15%, 0.3–1.5 mm) and rare quartz (up to 1.0 mm) in a recrystallized microfelsitic matrix (35–70%, 0.03–0.15 mm). Strong deformation is manifested by pulled-apart or augened phenocrysts, and local development of a differentiated layering. Compared to the Clearwater Lake Porphyry, muscovite is generally not as abundant, (although it may occur in amounts up to 45%), calcite is observed in a greater percentage of samples, and chlorite is rare. Biotite (5–10%) is found in some samples. Accessory minerals include zircon (present in all thin sections, and more common than in other intrusive rocks), apatite, epidote, titanite and Fe–Ti oxides.

The Barracks Brook Granite is, in general, petrographically similar to the Clearwater Lake Porphyry stocks, which are located 2–10 km to the north, except for the more common occurrence of plagioclase, particularly along its margins. The dominant porphyritic phase of the Barracks Brook Granite contains 0–35% alkali feldspar (0.5–3.0 mm), 5–35% plagioclase (0.4–3.0 mm) and rare quartz phenocrysts in a recrystallized felsitic matrix (25–55%, 0.05–0.15 mm). Muscovite (0–35%) and biotite (0–15%) are present in virtually all thin sections, whereas chlorite and calcite are less common. Accessory minerals are apatite, zircon and titanite. An equigranular variant in the southeastern part of the Barracks Brook pluton contains 50–60% alkali feldspar with patch-perthite texture (0.3–2.0 mm), 10–20% plagioclase (0.4–1.0 mm), 15–20% quartz (0.05–0.15 mm), 10–15% biotite, and minor muscovite replacing plagioclase. Large primary biotite crystals are partially altered to chlorite and contain inclusions of zircon and monazite. Allanite is present as rare crystals about 0.5 mm in length.

## GEOCHEMISTRY

### *Analytical methods*

Major oxides and trace elements (Rb, Ba, Sr, Ga, Zr, Y, Nb, Cr, Ni, V, Zn, Pb and Cu) were analyzed by X-ray fluorescence using fused discs (majors) and pressed powder pellets (traces). Rare-earth elements (REE), Sc, Hf, Ta, Co, Th and U, were analyzed by instrumental neutron activation analysis. All analyses were carried out at the Regional Geochemical Centre at St. Mary's University in Halifax, Nova Scotia. Analytical accuracy and precision were determined by comparison with recommended values for felsic, mafic and sedimentary rock standards used by the New Brunswick Geological Surveys Branch (Lentz 1995). In most cases, analytical error in accuracy and precision for major oxides, trace elements and REEs was well below 10%; however, poor reproducibility and accuracy were found for low-abundance elements such as Cr, Ni, Co, Cu and Pb, and, to a lesser extent, V, Ta, Th and U (> or >> 10%).

Two hundred and forty-seven (247) samples were collected for lithogeochemical analysis, including 112 felsic volcanic rocks, 60 felsic subvolcanic and plutonic rocks, 36 mafic volcanic rocks, 3 mafic intrusive rocks, 26 sedimentary rocks, and 10 samples of ironstone or red shale/chert exhalites. Felsic intrusive rocks do not include samples of Late Silurian–Early Devonian plutons, which were not addressed in this study. These data have been grouped according to formation or intrusion, and averages and standard deviations calculated, for easy comparison between different units (Tables 1–5). The discrepancy in the total number of samples reported in Tables 1–5, compared to the figures given above, are in most cases a result of hydrothermally altered samples being excluded from the averaging. Analytical data for individual samples are presented in Appendix 1; locations of these samples are plotted on digital 1:20 000 map files (Fyffe 1992, 1993, 1995b; Fyffe and Wilson 1994a, 1994b; Wilson 1993a, 1995b, 1995c).

### *Felsic volcanic rocks*

Average compositions of felsic volcanic rocks in the Big Bald Mountain area are presented in Table 1; the variations in major-oxide, trace-element and REE contents among the respective formations are illustrated graphically in Figures 3 and 4. Felsic volcanic rocks from both the Tetagouche and Sheephouse Brook groups span a range from dacitic to rhyolitic compositions based on alkali and silica contents. In the Sheephouse Brook Group, felsic volcanic rocks make up the bulk of the Clearwater Stream and Sevogle River formations, and a small part of the Slacks Lake Formation. In terms of silica content, the Clearwater Stream Formation is dacitic, whereas the Sevogle River Formation is rhyodacitic to rhyolitic, which is consistent with their respective distribution in the dacite to rhyolite fields on a Nb/Y vs. Zr/TiO<sub>2</sub> diagram (Figure 3a). Although there are significant differences in the abundance of major oxides and some trace elements (e.g., Cr, Ni, Co, Sc and V) between the Sevogle River and Clearwater Stream formations, their contents of high-field-strength elements (HFSE) and REEs are very similar (Table 1). Some of the samples from the Sevogle River Formation have much higher Nb/Y, suggesting a peralkaline affinity; however, these samples have only somewhat elevated Zr levels, and show a considerable variation from very high to very low REE (see samples O/1G-77, -78, -79 and -88, Appendix 1). These rocks possibly represent a transitional group between early calc-alkaline and later peralkaline felsic volcanism. The latter is expressed by felsic volcanic rocks from the Slacks Lake Formation, which plot in the comendite field on a Nb/Y vs. Zr/TiO<sub>2</sub> diagram (Figure 3a), and have elevated contents of all HFSE and REE (Table 1).

In the Tetagouche Group, felsic volcanic rocks make up most of the Flat Landing Brook Formation and about half of the Nepisiguit Falls Formation. The Nepisiguit Falls and Flat Landing Brook formations are rhyolites in terms of their major oxides (Table 1). With respect to trace-element distribution, Nepisiguit

Table 1. Average Compositions of Felsic Volcanic Rocks in the Big Bald Mountain Area.

Formation n	CW 15		SR 31		NF 19		FLv 18		FLt 2		SK 12	
	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
(wt%)												
SiO <sub>2</sub>	64.75	4.89	69.02	3.73	73.36	2.76	73.28	3.86	67.93	3.53	69.58	4.21
TiO <sub>2</sub>	0.70	0.21	0.40	0.18	0.35	0.12	0.35	0.17	0.59	0.00	0.43	0.21
Al <sub>2</sub> O <sub>3</sub>	15.18	2.07	14.57	1.51	13.38	0.94	13.04	1.27	13.26	1.24	13.44	2.25
Fe <sub>2</sub> O <sub>3</sub>	5.45	1.80	3.24	1.01	2.93	1.25	2.96	1.30	5.52	1.16	5.21	2.23
MnO	0.07	0.03	0.06	0.05	0.06	0.04	0.07	0.03	0.06	0.01	0.07	0.03
MgO	3.11	1.20	1.91	1.20	1.14	0.70	1.13	0.68	3.17	1.97	1.11	1.21
CaO	1.53	1.10	0.58	0.81	0.38	0.41	0.54	0.64	1.61	0.57	0.34	0.43
Na <sub>2</sub> O	2.10	1.07	1.87	1.30	2.66	1.32	3.17	1.58	2.88	1.25	2.88	1.76
K <sub>2</sub> O	3.26	1.32	5.47	2.79	3.67	1.45	3.43	1.44	1.91	0.66	4.91	2.30
P <sub>2</sub> O <sub>5</sub>	0.28	0.34	0.11	0.06	0.12	0.03	0.07	0.05	0.18	0.01	0.07	0.08
LOI	3.19	0.90	1.96	0.94	1.54	0.81	1.34	0.68	2.75	0.49	1.33	1.05
(ppm)												
Cr	25	6	15	11	33	41	17	5	19	1	12	8
Ni	8	4	4	2	13	25	5	2	8	3	4	1
Co	9.2	5.4	4.0	5.0	7.9	10.0	5.5	6.8	4.6	0.9	7.3	7.3
Sc	17.0	3.7	10.9	5.4	6.8	2.9	10.3	4.2	15.8	1.9	8.1	8.1
V	71	36	26	24	33	27	27	28	28	7	10	18
Pb	20	9	27	21	17	13	16	10	12	10	21	17
Zn	81	19	94	136	47	34	69	69	106	6	128	64
Rb	106	56	153	67	114	36	123	47	58	41	100	43
Ba	681	236	743	338	568	180	571	185	1204	1067	616	432
Sr	100	75	77	63	52	20	48	20	154	105	54	49
Ga	20.2	3.5	20.9	4.8	14.7	3.2	15.7	3.2	21.8	2.5	30.8	6.6
Ta	1.45	0.30	1.85	1.47	0.94	0.26	1.27	0.19	3.07	0.32	5.86	3.39
Nb	19.2	3.0	26.5	24.1	10.1	1.4	14.0	3.0	41.4	2.0	103.4	49.6
Hf	9.04	1.49	9.23	2.36	4.78	1.26	7.06	1.38	13.07	0.59	18.94	8.17
Zr	316	58	319	72	153	26	236	55	438	7	882	336
Y	54.9	11.2	60.0	24.0	38.8	7.6	49.2	10.1	68.9	5.5	98.6	37.5
Th	20.0	2.9	22.6	4.9	14.5	3.7	17.2	3.1	19.0	2.6	17.7	5.1
U	4.2	1.2	5.5	2.0	3.7	1.0	4.1	0.7	2.3	0.2	4.4	1.4
La	55.11	22.77	55.86	38.25	29.73	14.34	54.94	32.33	73.06	6.33	96.70	39.51
Ce	113.45	21.69	108.70	41.97	63.53	20.70	95.13	20.28	150.28	18.86	191.50	54.30
Nd	51.96	20.71	51.09	28.56	28.19	12.70	49.00	30.77	75.65	9.05	99.40	39.86
Sm	10.56	3.41	10.28	4.64	6.12	2.52	9.86	4.53	14.61	1.59	19.21	6.96
Eu	1.62	0.62	1.23	0.57	0.79	0.38	1.38	0.61	2.89	0.25	3.12	1.97
Tb	1.77	0.53	1.80	0.70	1.05	0.35	1.53	0.41	2.29	0.40	3.29	1.09
Yb	5.44	1.04	5.92	2.33	3.31	0.87	4.52	0.86	5.98	0.41	9.96	3.34
Lu	0.76	0.14	0.89	0.40	0.47	0.12	0.67	0.14	0.84	0.09	1.43	0.49

Notes: CW—Clearwater Stream Formation; SR—Sevogle River Formation; NF—Nepisiguit Falls Formation; FLv, FLt—Flat Landing Brook Formation, rhyolite and crystal tuff, respectively; SK—Slacks Lake Formation; Avg.—average; SD—standard deviation; n— number of samples.

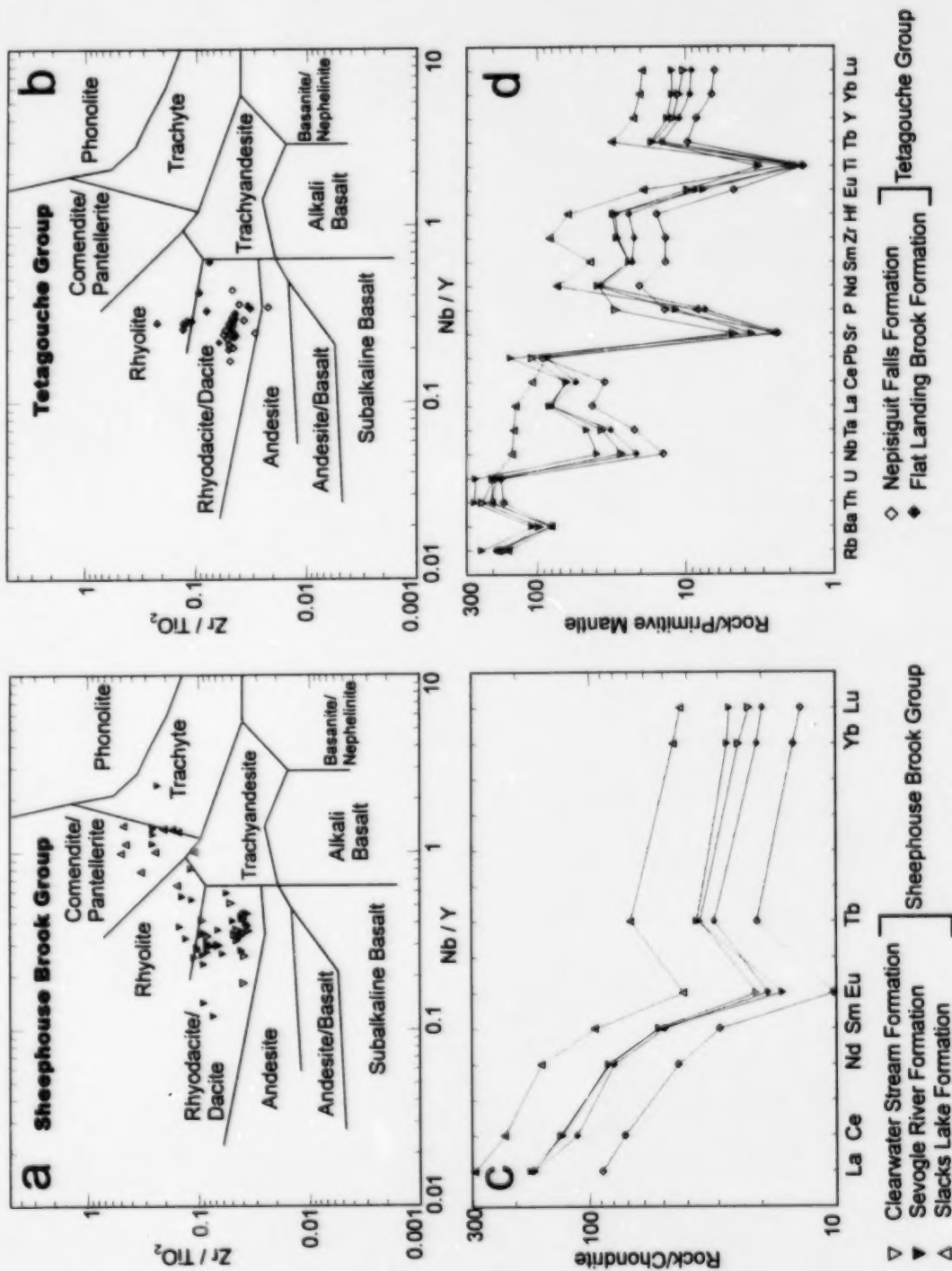


Figure 3. (a) and (b) Nb/Y vs. Zr/TiO<sub>2</sub> trace-element variation diagrams (Winchester and Floyd 1977) for felsic volcanic rocks in the Big Bald Mountain area, showing distribution of samples from the Sheephouse Brook Group and Tetagouche Group, respectively. (c) Chondrite-normalized REE plot of average compositions of felsic volcanic rocks from the Big Bald Mountain area. Chondrite-normalizing values are from Sun (1982). (d) Primitive-mantle-normalized trace-element spidergram for felsic volcanic rocks from the Big Bald Mountain area. Primitive-mantle-normalizing values are from Sun and McDonough (1989).

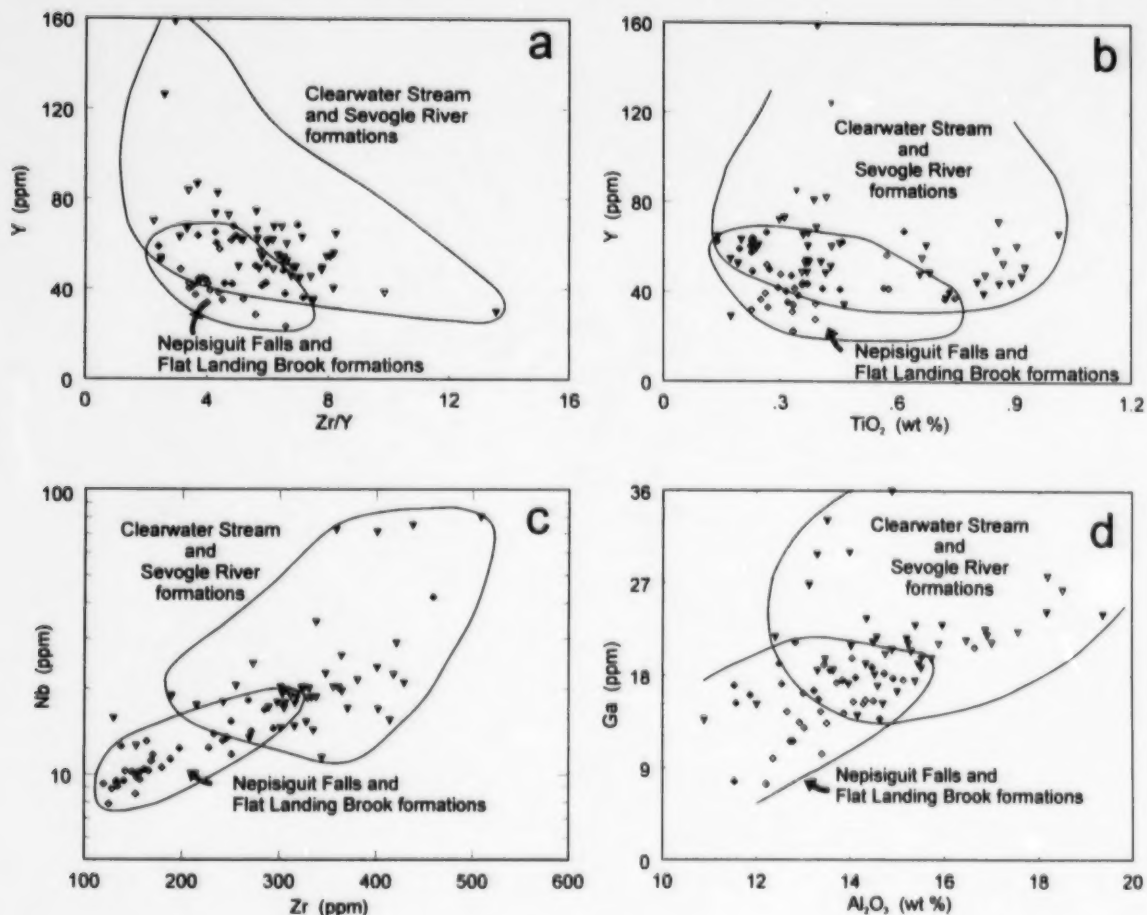


Figure 4. Major- and trace-element bivariate plots for felsic volcanic rocks in the Tetagouche and Sheephouse Brook groups: (a) Zr/Y vs. Y; (b)  $\text{TiO}_2$  vs. Y; (c) Zr vs. Nb; (d)  $\text{Al}_2\text{O}_3$  vs. Ga. Symbols as in Figure 3.

Falls rocks plot in the dacitic field, and Flat Landing Brook rocks span the rhyolite/rhyodacite boundary on a Nb/Y vs. Zr/ $\text{TiO}_2$  diagram (Figure 3b). In contrast to the Clearwater Stream and Sevogle River formations (Sheephouse Brook Group), the Nepisiguit Falls and Flat Landing Brook formations have strikingly similar major-element abundances, but differ in their content of most HFSE and REE. Compared to the Nepisiguit Falls Formation, the Flat Landing Brook Formation has higher Ta, Nb, Hf, Zr, Y, Th and REE, which is consistent with previous lithogeochemical studies on these rocks (e.g., Langton and McCutcheon 1993; Wilson 1993b; Lentz 1999). Thin beds of crystal tuff are interbedded with tholeiitic basalt in the upper part of the Flat Landing Brook Formation; these tuffs have greater trace-element abundances than the rhyolites (Table 1) and appear to be compositionally transitional to the peralkaline felsic rocks that are intercalated with alkalic basalts in the upper part of the Tetagouche Group (van Staal *et al.* 1991).

Variation in trace-element composition is illustrated on REE and trace-element spidergrams (Figure 3c and d), and on bivariate plots of selected oxides and elements (Figure 4). The most striking feature of

these diagrams is the markedly higher and lower contents, respectively, of REE and most other trace elements in felsic volcanic rocks of the Slacks Lake and Nepisiguit Falls formations, compared to the Flat Landing Brook, Clearwater Stream and Sevogle River formations (Figure 3c, d). Felsic volcanic rocks from the latter three units are tightly clustered, although the Flat Landing Brook Formation has marginally lower contents of most elements. Tetagouche felsic volcanic rocks are distinguished by lower abundances of several groups of elements, including REE, large-ion lithophile elements (LILE—Ba, Rb, Sr, Pb) and HFSE (Ti, Sc, Y, Nb, Ta, Zr, Hf, Th, U), as well as Ga and Zn (Figure 3d; Figure 4; Table 1).

Felsic volcanic rocks in the Sheephouse Brook and Tetagouche groups can also be distinguished using selected trace-element ratios. For example, almost 75% of Nepisiguit Falls and Flat Landing Brook rocks have  $Zr/Y < 5$ , whereas 75% of Clearwater Stream and Sevogle River samples have  $Zr/Y > 5$  (Figure 4a). Similarly, Nb/Y in the Tetagouche Group is typically  $< 0.30$ , Rb/Sr  $> 2.0$ , and Ba/Sr  $> 10.0$ , whereas these ratios in felsic volcanic rocks of the Sheephouse Brook Group are typically  $> 0.30$ ,  $< 2.0$  and  $< 10.0$ , respectively. Consistent differences also appear in Nb/Ta and Zr/Hf ratios: in the Flat Landing Brook and Nepisiguit Falls formations, Zr/Hf (average 33.4 and 32.0, respectively) and Nb/Ta (average 11.0 and 10.7, respectively) are typically lower than in the Sevogle River and Clearwater Stream formations (average Zr/Hf values are 34.6 and 35.0; average Nb/Ta values are 14.3 and 13.2, respectively). These variations in Nb/Ta and Zr/Hf may reflect a contrast in the crustal sources of volcanic rocks between the southern and central parts of the Bathurst Mining Camp.

### ***Felsic intrusive rocks***

Felsic intrusive rocks have been divided into a subvolcanic group (porphyries) and a plutonic group that is characterized by granitic textures, although the Barracks Brook Granite has both porphyritic and equigranular phases. Statistical and graphical data for the porphyritic rocks are presented, respectively, in Table 2 and Figures 5a and c; and for the plutonic rocks, in Table 3 and Figures 5b and d. It is clear that all felsic intrusive suites are compositionally similar; nearly all samples plot in the rhyodacite/dacite field on a Nb/Y vs. Zr/TiO<sub>2</sub> diagram (Figures 5a and b), and display virtually identical profiles on an extended trace-element spiderplot (Figures 5c and d). Porphyritic rocks show some enrichment in Pb, and slightly higher Sr and Ti compared to plutonic rocks. Among plutonic rocks, the South Little River Lake Granite is somewhat anomalous in its lower abundances of Ti, Zr, Sr and P, although this is based on only two analyses (Heath Steele Granite; Whalen 1993). Moreover, comparison with Figure 3 suggests that felsic intrusive and volcanic rocks have a common petrogenesis: except for the peralkaline rocks from the Slacks Lake Formation, volcanic rocks display trace-element profiles (Figure 3d) with shapes and slopes very similar to the intrusive rocks. Like the porphyries, volcanic rocks feature the Pb "spike" referred to above.

Most intrusive rocks are located south of the Moose Lake–Tomogonops and Mountain Brook faults, so a genetic relationship may be expected with felsic volcanic rocks of the Sheephouse Brook Group. Though not definitive, there is some indication that such a relationship may exist between the Clearwater Stream Formation and Squirrel Falls Porphyry, and between the Sevogle River Formation and Clearwater Lake Porphyry. These respective pairs of units have similar major- and trace-element abundances, and occupy the same parts of the Nb/Y vs. Zr/TiO<sub>2</sub> diagram (compare Figures 3a and 5a). Clearwater Stream and Squirrel Falls samples plot in the same parts of Zr/Ti vs. Y/Ti and Ti/V vs. Zr/V diagrams (Figures 6a and b), as do samples from the Sevogle River Formation and Clearwater Lake Porphyry. Although some overlap exists in the Squirrel Falls/Clearwater Stream and the Clearwater Lake/Sevogle River fields, distinct areas of high point density indicate different trace-element systematics for the respective groups.

**Table 2. Average Compositions of Subvolcanic Porphyritic Rocks in the Big Bald Mountain Area.**

Formation n	STB 10		SQF 17		CLW 16	
	Avg.	SD	Avg.	SD	Avg.	SD
<b>(wt%)</b>						
SiO <sub>2</sub>	71.13	3.29	68.92	2.40	70.82	3.35
TiO <sub>2</sub>	0.34	0.16	0.61	0.20	0.37	0.20
Al <sub>2</sub> O <sub>3</sub>	13.76	1.30	14.78	0.47	14.04	1.33
Fe <sub>2</sub> O <sub>3</sub>	3.02	0.94	4.86	1.40	2.86	1.23
MnO	0.05	0.03	0.07	0.04	0.05	0.03
MgO	1.19	0.54	1.47	0.62	1.21	0.84
CaO	0.47	0.24	0.78	1.04	0.54	0.63
Na <sub>2</sub> O	1.84	0.98	4.04	1.54	2.08	0.71
K <sub>2</sub> O	6.09	1.33	2.40	1.39	5.38	2.34
P <sub>2</sub> O <sub>5</sub>	0.22	0.09	0.17	0.07	0.15	0.05
LOI	1.39	0.56	1.61	0.52	1.83	0.63
<b>(ppm)</b>						
Cr	17	5	34	19	13	7
Ni	5	2	11	6	4	3
Co	2.4	1.9	6.7	4.0	9.8	11.8
Sc	14.7	4.3	13.5	4.6	12.7	4.4
V	19	17	62	28	27	25
Pb	23	12	18	27	22	11
Zn	60	15	57	20	53	20
Rb	173	54	90	51	169	61
Ba	632	262	496	252	665	272
Sr	46	12	131	130	101	138
Ga	17.8	4.0	15.6	3.4	16.7	7.1
Ta	1.38	0.21	1.40	0.90	1.51	0.29
Nb	16.6	3.0	20.6	15.1	17.2	2.9
Hf	7.49	2.36	7.89	1.67	7.35	1.90
Zr	239	96	271	67	248	81
Y	72.7	20.6	45.8	15.0	54.3	12.0
Th	20.4	6.5	17.4	3.8	20.9	4.9
U	5.7	1.5	4.3	1.3	5.1	1.5
<b>(ppm)</b>						
La	53.72	27.60	47.82	23.53	42.38	25.33
Ce	110.90	55.63	94.06	39.74	96.85	22.22
Nd	53.40	24.15	44.90	20.51	39.71	17.74
Sm	11.88	4.41	8.51	3.67	8.48	2.40
Eu	1.03	0.46	1.43	0.54	1.05	0.91
Tb	1.94	0.50	1.36	0.54	1.69	0.46
Yb	6.38	1.90	4.58	1.69	5.48	1.09
Lu	0.89	0.26	0.65	0.23	0.76	0.18

Notes: STB—Stony Brook Porphyry; SQF—Squirrel Falls Porphyry; CLW—Clearwater Lake Porphyry; Avg.—average; SD—standard deviation; n—number of samples.

Table 3. Average Compositions of Intrusive Rocks in the Big Bald Mountain Area.

Formation n	BBK 9		MEB 2		MUS 3		SLR(W) 2	MEB(W) 10	MUS(W) 8
	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	Avg.	Avg.
(wt%)									
SiO <sub>2</sub>	72.88	3.00	71.80	0.57	72.04	3.24	75.93	69.81	72.71
TiO <sub>2</sub>	0.29	0.19	0.34	0.09	0.37	0.17	0.16	0.42	0.27
Al <sub>2</sub> O <sub>3</sub>	13.13	1.13	12.97	0.19	14.13	0.71	12.10	14.65	13.37
Fe <sub>2</sub> O <sub>3</sub>	2.83	1.00	5.36	1.69	3.09	1.65	1.13	2.92	2.17
MnO	0.04	0.02	0.09	0.01	0.04	0.01	0.01	0.05	0.05
MgO	0.70	0.54	1.03	0.05	0.68	0.51	0.25	0.61	0.31
CaO	0.30	0.15	0.99	0.98	1.00	1.23	0.39	1.37	0.98
Na <sub>2</sub> O	3.04	1.33	1.27	1.62	3.80	0.26	3.24	3.79	3.75
K <sub>2</sub> O	4.67	1.54	3.74	0.42	3.24	1.04	5.01	5.20	4.53
P <sub>2</sub> O <sub>5</sub>	0.18	0.10	0.18	0.12	0.11	0.04	0.03	0.11	0.09
LOI	0.94	0.44	1.75	1.20	1.17	0.38	0.87	0.79	1.04
(ppm)									
Cr	15	9	10	1	28	9	1	7	4
Ni	6	3	6	1	6	5	2	0	2
Co	2.8	2.7	4.2	2.1	3.8	2.5	1.2	4.0	2.8
Sc	11.6	5.6	20.2	3.0	11.4	3.0	14.2	11.9	6.9
V	18	21	15	4	38	31	3	31	17
Pb	11	12	34	47	18	1	12	14	9
Zn	56	23	74	30	43	5	14	21	50
Rb	136	47	167	16	84	12	133	177	144
Ba	495	147	547	162	759	248	755	568	599
Sr	35	11	67	76	164	135	22	104	83
Ga					17.3	0.6	17.5	18.6	19.3
Ta	1.63	1.00	1.30	0.28	1.06	0.16	1.68	1.20	1.69
Nb	27.4	16.4	23.5	2.1	13.3	2.5	26.0	18.4	23.0
Hf	7.64	3.28	7.15	1.06	6.26	0.56	5.85	8.29	7.00
Zr	261	130	280	36	197	9	144	259	194
Y	56.8	10.3	56.0	2.8	41.7	13.0	76.5	58.6	59.0
Th	16.9	3.1	17.2	1.5	15.5	1.9	22.3	21.8	16.8
U	5.5	0.9	4.9	1.3	3.3	0.3	5.1	5.5	4.2
La	51.63	27.16	51.50	10.61	54.15	21.78	64.50	60.40	55.75
Ce	104.02	44.95	114.00	8.49	96.15	26.30	123.50	106.50	98.25
Nd	51.36	21.07	53.00	1.41	47.51	15.84	60.05	47.24	42.98
Sm	9.51	2.63	10.95	0.35	9.49	3.46	11.68	9.23	8.59
Eu	1.24	0.74	1.59	0.64	1.45	0.14	1.06	1.27	1.24
Tb	1.90	0.41	1.70	0.00	1.30	0.49	2.05	1.59	1.52
Yb	6.70	1.32	6.80	0.64	3.99	1.06	6.80	4.88	5.06
Lu	0.88	0.15	0.87	0.07	0.57	0.14	0.98	0.70	0.73

Notes: BBK—Barracks Brook Granite; MEB—Meridian Brook Granite; MUS—Mullin Stream Lake Granite; SLR(W), MEB(W), MUS(W)—average compositions of South Little River Lake (Heath Steele) Granite, Meridian Brook Granite and Mullin Stream Lake Granite from Whalen (1993). Avg.—average; SD—standard deviation; n—number of samples.

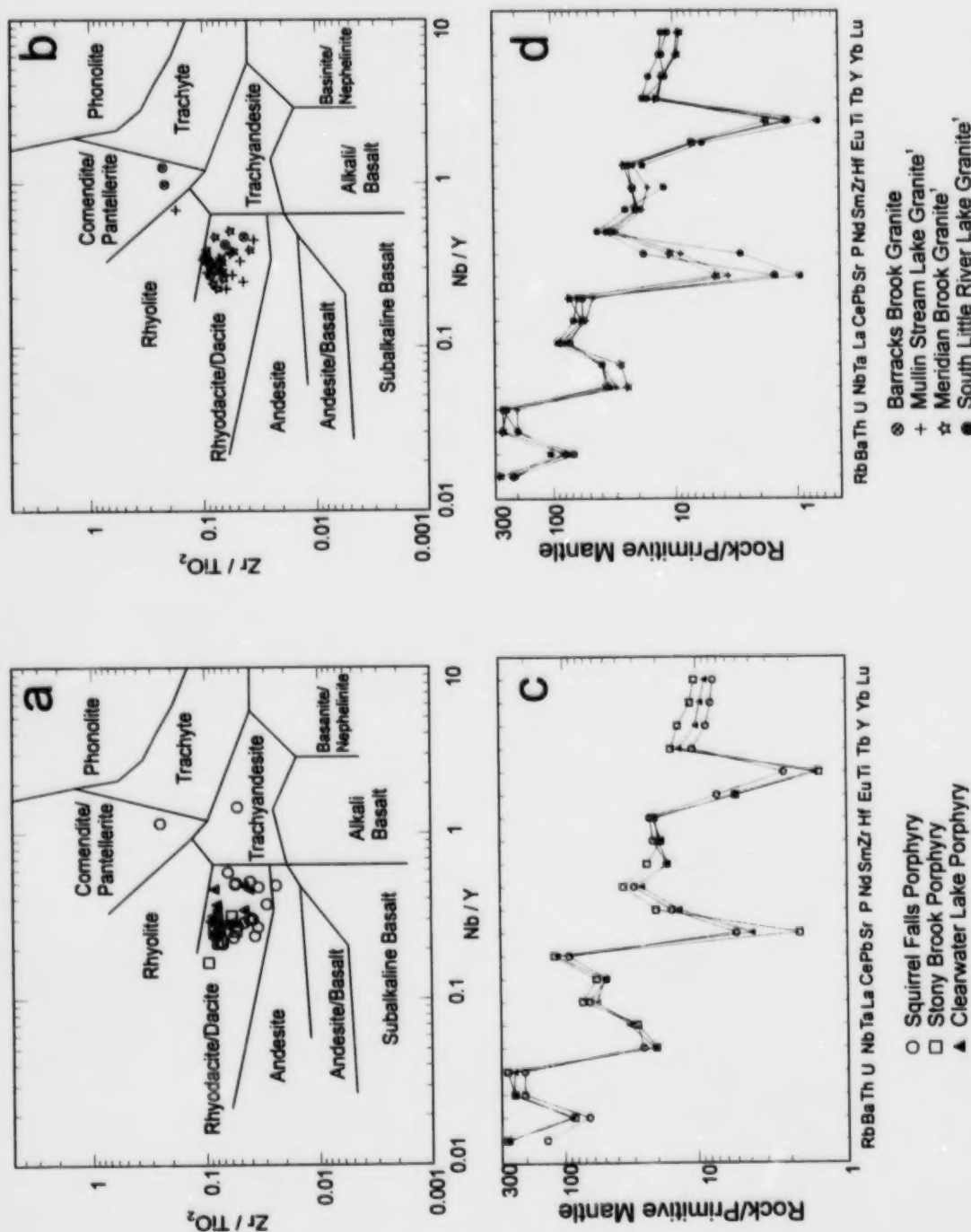


Figure 5. (a) and (b) Nb/Y vs. Zr/TiO<sub>2</sub> trace-element variation diagrams (Winchester and Floyd 1977) for felsic intrusive rocks in the Big Bald Mountain area, showing distribution of samples from porphyritic subvolcanic rocks and plutonic rocks, respectively. (c) and (d) Primitive-mantle-normalized trace-element spidergram for porphyritic subvolcanic rocks and plutonic rocks, respectively, from the Big Bald Mountain area. Primitive-mantle normalizing values are from Sun and McDonough (1989). <sup>1</sup> Data from Whalen (1993).

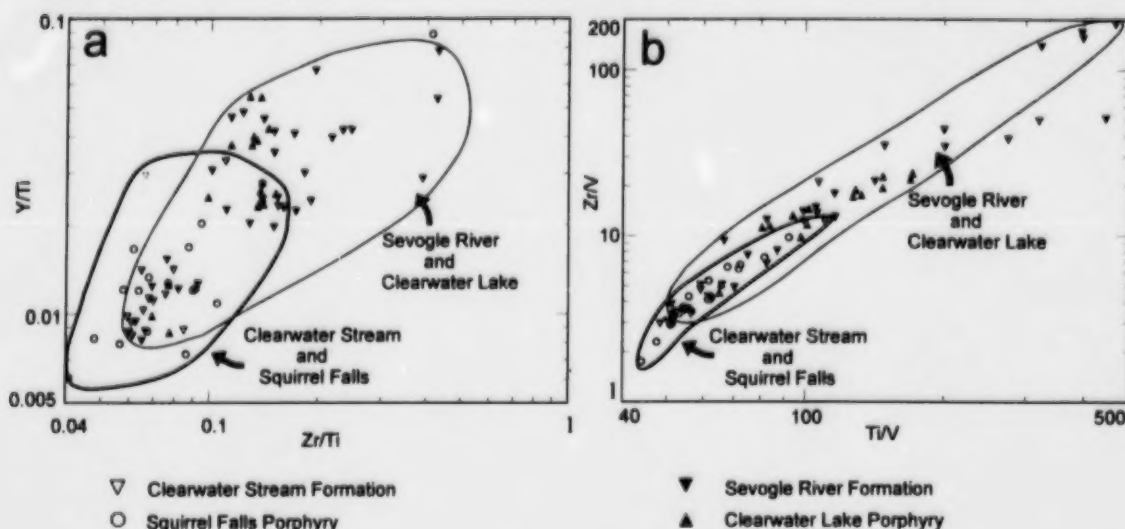


Figure 6. (a) Zr/Ti vs. Y/Ti diagram, and (b) Ti/V vs. Zr/V diagram for felsic rocks from the Clearwater Lake Porphyry, Squirrel Falls Porphyry, Sevogle River Formation, and Clearwater Stream Formation.

### Mafic volcanic rocks

Mafic volcanic rocks in the Big Bald Mountain area have been separated into five suites from three formations: (1) alkali basalts, (2) trachyandesites, and (3) sub-alkaline (tholeiitic) basalts of the Slacks Lake Formation; (4) alkali basalt from the Brunswick Mines Member of the Little River Formation; and (5) tholeiitic basalt from the Forty Mile Brook Member of the Flat Landing Brook Formation (Figure 7a). Average compositions for each suite are presented for comparison in Table 4. The Forty Mile Brook tholeiite displays mid-ocean ridge basalt (MORB)-like affinities, with low Nb/Y (0.2), Zr, LILE and light REE, flat REE profiles (average La/Yb = 1.7), and relatively high Cr, Ni and V (Figures 7b, c, and d; Table 4). Chemically, it is virtually identical to the Forty Mile Brook tholeiite of van Staal *et al.* (1991). Compared to the Forty Mile Brook tholeiite, sub-alkalic basalts in the Slacks Lake Formation have much lower Cr, Ni and Y, higher Nb/Y (0.4), LILE and light REE abundances, and lower heavy REE (i.e., a steeper REE profile, with average La/Yb = 5.3; Figure 7d). On the Nb–Zr–Y ternary diagram (Meschede 1986), Slacks Lake sub-alkaline basalts plot in the within-plate tholeiite field (Figure 7b).

Alkali basalts and trachyandesites have Nb/Y > 0.6, TiO<sub>2</sub> > 2%, relatively high HFSE and REE contents, and steep REE profiles (average La/Yb 7.9–9.3) compared to tholeiitic basalts (Table 4; Figure 7a, c and d); they plot in the transitional within-plate alkali basalt field on a Nb–Zr–Y diagram (Figure 7b). Compared to the Brunswick Mines (Little River Formation) alkali basalts, alkali basalts in the Slacks Lake Formation have much higher P<sub>2</sub>O<sub>5</sub>, and higher TiO<sub>2</sub>, REE and HFSE; the slopes of REE profiles from the two units are very similar (La/Yb = 8.6 for the Brunswick Mines alkalic basalts, and 9.3 for the Slacks Lake alkalic basalts). In the Big Bald Mountain area, basalts assigned to the Brunswick Mines Member have significantly more Cr and Ni, and lower Ba, Sr, HFSE and REE than the Brunswick basalts of van Staal *et al.* (1991), although most inter-element ratios are very similar. Van Staal *et al.* (1991) documented several suites of alkalic basalt in the Tetagouche Group, based on slight variations in Cr content and trace-element ratios; therefore, there may be some justification for separate member status for the Little River basalts underlying the northeast corner of the survey area.

Table 4. Average Compositions of Mafic Volcanic Rocks in the Big Bald Mountain Area.

Formation n	SK (alk) 15		SK (tra) 4		SK (tho) 8		LRBM 5		FLFM 4	
	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
(wt%)										
SiO <sub>2</sub>	45.36	2.88	57.18	2.05	47.68	2.89	44.57	3.74	46.67	1.10
TiO <sub>2</sub>	2.90	0.58	1.09	0.27	1.71	0.62	2.59	0.38	1.99	0.65
Al <sub>2</sub> O <sub>3</sub>	14.98	1.30	15.02	1.16	17.09	0.82	14.97	1.25	14.28	0.92
Fe <sub>2</sub> O <sub>3</sub>	12.82	2.05	11.98	2.82	10.93	1.49	12.85	2.28	12.85	1.65
MnO	0.23	0.07	0.17	0.05	0.22	0.12	0.16	0.02	0.20	0.03
MgO	6.10	1.75	4.05	1.97	5.68	0.96	6.99	2.88	7.51	0.21
CaO	7.86	3.32	2.23	0.67	8.41	1.81	7.23	2.32	8.50	1.73
Na <sub>2</sub> O	3.14	1.22	3.95	1.77	4.01	1.60	3.33	1.61	2.80	1.03
K <sub>2</sub> O	0.69	0.71	1.26	0.16	0.85	0.50	0.66	0.42	0.21	0.17
P <sub>2</sub> O <sub>5</sub>	0.65	0.41	0.27	0.17	0.22	0.09	0.32	0.07	0.20	0.08
LOI	5.45	2.43	3.73	1.66	2.58	2.79	6.62	1.66	4.93	1.68
(ppm)										
Cr	164	143	59	102	107	109	200	130	399	145
Ni	74	60	18	28	53	53	71	29	146	64
Co	39.0	9.1	9.0	9.9	41.0	13.9	46.0	7.4	45.8	6.4
Sc	31.3	5.8	26.9	5.1	33.4	4.5	34.4	4.4	39.9	4.1
V	295	103	34	63	310	40	345	94	370	94
Pb	11	4	11	5	14	9	7	4	5	0
Zn	127	41	211	48	90	10	109	19	108	21
Rb	14	15	42	8	21	21	10	4	6	2
Ba	257	166	589	435	205	153	171	136	36	26
Sr	344	235	174	124	254	70	166	58	154	62
Ga	22.5	3.7	29.5	5.9	18.3	1.6	17.1	5.4	13.8	3.2
Ta	2.50	1.26	3.97	0.68	0.72	0.35	1.38	0.37	0.51	0.21
Nb	35.8	17.2	61.0	16.3	9.8	7.2	23.4	1.7	8.8	2.2
Hf	6.05	2.38	16.74	6.75	3.03	1.20	4.44	0.74	3.58	1.21
Zr	257	92	748	308	128	48	187	33	125	37
Y	44.8	19.6	90.8	25.5	24.4	6.9	30.9	4.9	46.5	14.8
Th	2.9	1.0	9.3	1.7	2.1	1.0	1.8	0.4	0.6	0.1
U	1.0	0.6	2.1	0.5	0.7	0.3	0.5	0.5	0.5	0.2
La	31.44	13.93	64.47	17.57	13.87	3.65	19.46	4.07	6.80	2.59
Ce	68.92	31.32	134.58	27.24	31.35	7.19	40.97	4.89	18.29	6.96
Nd	39.15	17.83	74.07	23.61	18.51	3.58	23.21	3.05	13.33	4.25
Sm	8.74	3.81	16.64	4.56	4.31	0.90	5.50	0.87	4.77	1.43
Eu	2.88	1.21	4.76	1.32	1.43	0.33	2.09	0.47	1.59	0.43
Tb	1.35	0.51	2.48	0.55	0.72	0.25	0.88	0.26	0.96	0.33
Yb	3.39	1.35	8.15	2.06	2.64	0.88	2.27	0.49	3.96	1.10
Lu	0.50	0.20	1.13	0.28	0.36	0.11	0.35	0.07	0.60	0.17

Notes: SK(alk), SK(tra), SK(tho)—alkalic basalts, trachyandesites, and tholeiitic basalts, respectively, from the Stacks Lake Formation; LRBM—Little River Formation (Brunswick Mines Member); FLFM—Flat Landing Brook Formation (Forty Mile Brook Member); Avg.—average; SD—standard deviation; n—number of samples.

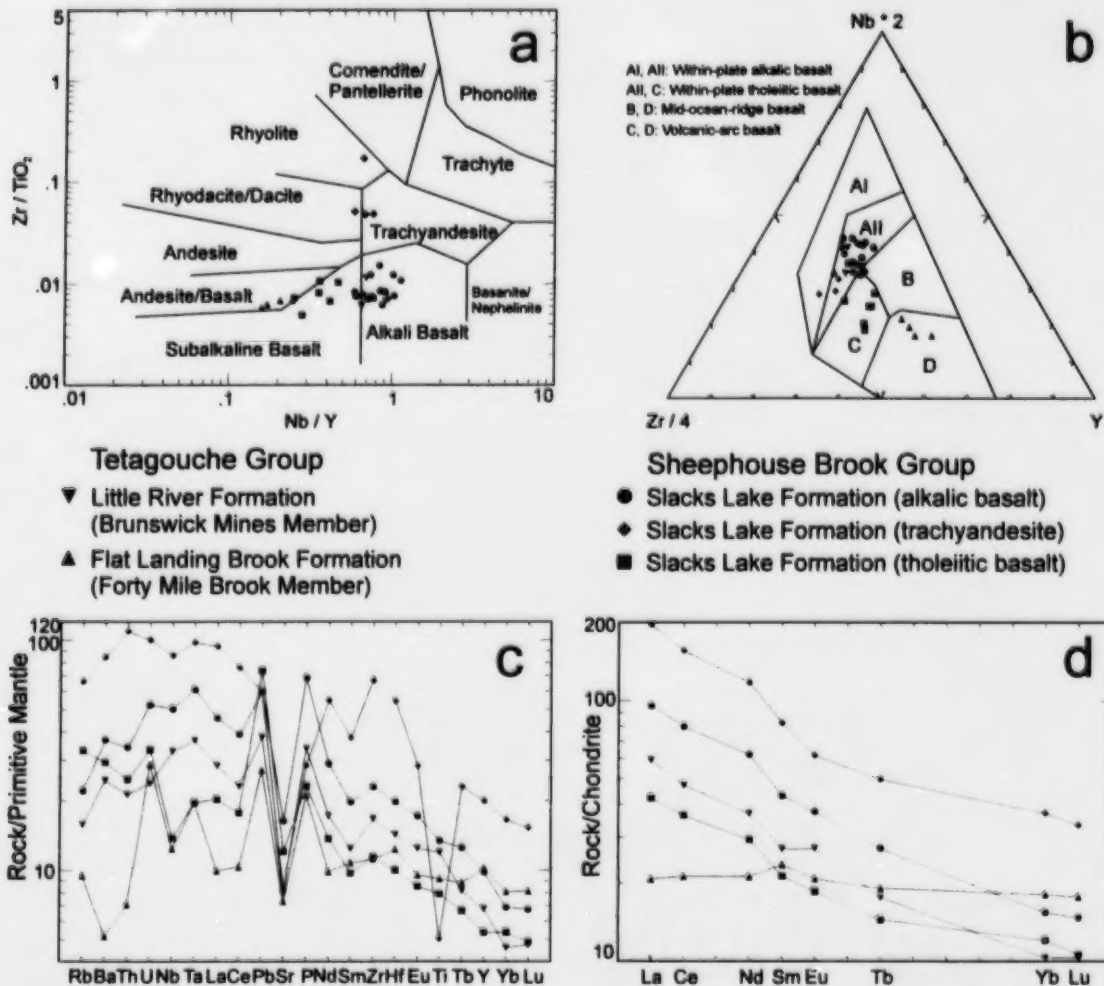


Figure 7. Trace-element variation diagrams for mafic volcanic rocks from the Big Bald Mountain area. (a) Nb/Y vs. Zr/TiO<sub>2</sub> diagram (Winchester and Floyd 1977); (b) Nb-Y-Zr tectonic discrimination diagram (Meschede 1986); (c) primitive-mantle-normalized trace-element spidergram; normalizing factors are from Sun and McDonough (1989); (d) chondrite-normalized REE profiles; normalizing factors are from Sun (1982).

### Sedimentary rocks

Sedimentary rocks comprise four suites, namely older rocks from the Patrick Brook Formation (Miramichi Group) and the lower part of the Nepisiguit Falls Formation (Little Falls Member, near the base of the Tetagouche Group), and younger rocks from the Sevogle River and Slacks Lake Formation (Sheephouse Brook Group). An effort was made to collect fine-grained samples from each unit in order to facilitate comparison; however, as revealed by their silica contents, samples from the Sevogle River Formation were somewhat more quartzose on average, compared to the Nepisiguit Falls and Patrick Brook formations, and samples collected from the Slacks Lake Formation were graphitic cherts (Table 5). Inter-unit variations in major- and trace-element abundances covary depending on silica content, so direct comparison of absolute abundances is relatively meaningless. However, trace-element profiles (Figure 8a) and a variation

Table 5. Average Compositions of Sedimentary Rocks in the Big Bald Mountain Area.

Formation n	PB 8		NFLF 9		SR 4		SK 4	
	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
(wt%)								
SiO <sub>2</sub>	58.39	7.28	63.35	7.88	68.76	9.94	88.67	2.97
TiO <sub>2</sub>	1.09	0.13	0.96	0.16	0.61	0.19	0.31	0.08
Al <sub>2</sub> O <sub>3</sub>	20.05	3.48	16.68	3.51	13.90	3.91	5.32	1.39
Fe <sub>2</sub> O <sub>3</sub>	8.22	1.02	7.80	2.00	5.24	3.41	0.33	0.07
MnO	0.10	0.06	0.28	0.54	0.09	0.10	0.01	0.00
MgO	2.16	0.69	2.19	0.54	2.01	0.84	0.35	0.11
CaO	0.07	0.05	0.41	0.48	0.20	0.32	0.01	0.02
Na <sub>2</sub> O	1.02	0.78	1.41	0.98	0.81	0.83	0.29	0.27
K <sub>2</sub> O	4.45	1.23	3.21	1.00	3.67	1.78	1.46	0.48
P <sub>2</sub> O <sub>5</sub>	0.10	0.02	0.18	0.08	0.11	0.06	0.02	0.01
LOI	3.83	1.15	3.08	0.99	4.28	0.94	3.43	0.99
(ppm)								
Cr	122	16	111	36	108	13	63	11
Ni	30	6	30	16	25	11	4	2
Co	8.3	4.3	10.0	4.5	11.8	10.2	23.5	26.3
Sc	20.6	5.1	17.4	3.7	14.3	3.2	7.4	1.7
V	193	23	146	43	197	43	387	312
Pb	15	9	21	8	12	15	13	7
Zn	72	18	88	15	67	34	5	4
Rb	197	45	123	53	133	69	53	17
Ba	671	154	532	126	715	186	406	146
Sr	51	12	73	53	39	22	15	7
Ga	26.9	5.8	21.6	5.7	20.0	4.2	9.1	1.3
Ta	1.45	0.09	1.38	0.27	0.95	0.35	0.50	0.42
Nb	18.9	1.6	16.1	3.2	13.8	6.4	4.7	1.3
Hf	5.71	1.33	5.86	1.60	3.04	0.60	1.33	0.39
Zr	194	37	196	46	111	25	54	9
Y	38.6	7.4	31.6	9.9	31.8	13.0	18.8	4.5
Th	17.2	2.2	14.4	2.8	9.0	3.5	2.5	0.7
U	5.8	2.9	3.6	2.1	5.2	2.4	5.1	2.5
La	53.60	10.04	38.52	17.52	35.93	9.95	12.69	4.67
Ce	113.73	15.75	81.01	33.87	66.04	25.74	30.22	16.28
Nd	47.73	6.50	33.94	15.60	32.26	16.30	11.83	2.17
Sm	9.30	1.89	6.80	3.22	6.70	2.32	2.82	0.54
Eu	1.76	0.26	1.42	0.52	1.05	0.30	0.51	0.09
Tb	1.32	0.29	1.03	0.38	0.94	0.33	0.43	0.08
Yb	3.55	0.81	3.19	0.77	2.69	0.87	1.46	0.28
Lu	0.56	0.06	0.48	0.08	0.38	0.08	0.22	0.02

Notes: PB—Patrick Brook Formation; NFLF—Nepisiguit Falls Formation (Little Falls Member); SR—Sevogle River Formation; SK—Stacks Lake Formation; Avg.—average; SD—standard deviation; n—number of samples.

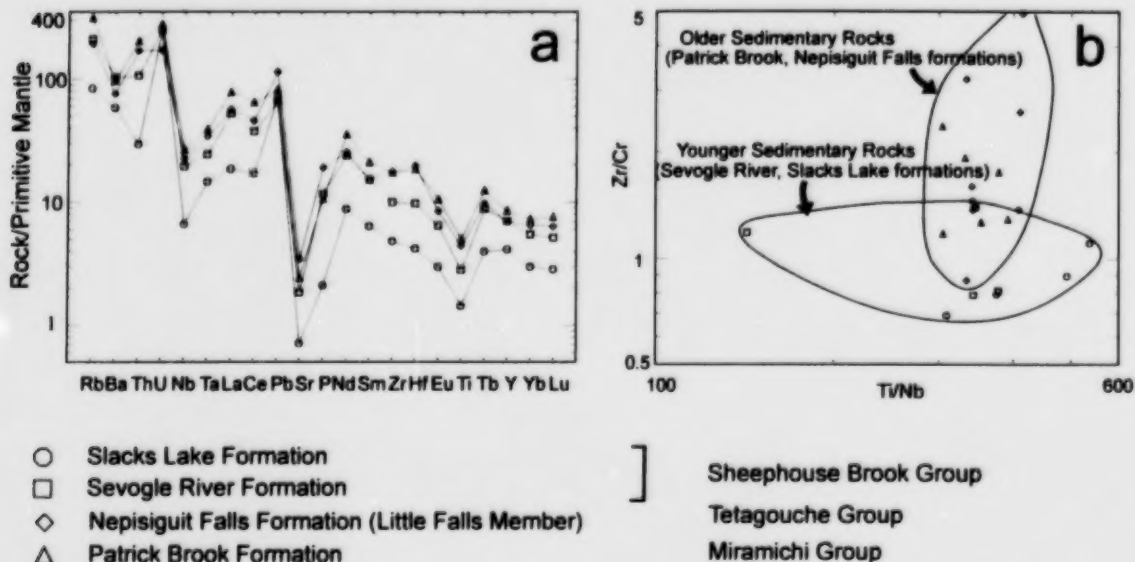


Figure 8. Trace-element variation diagrams for sedimentary rocks from the Big Bald Mountain area. (a) Primitive-mantle-normalized trace-element spidergram; normalizing factors are from Sun and McDonough (1989). (b) Ti/Nb vs Zr/Cr plot for discriminating felsic vs. mafic provenance.

diagram employing trace-element ratios (Figure 8b) provide more information. The shape and slope of the trace-element profiles show an essentially identical pattern of peaks and troughs, with minor exceptions, such as the negative Th anomaly in the Slacks Lake Formation, and the positive Zr and Hf anomalies in the Little Falls Member of the Nepisiguit Falls Formation (Figure 8a). However, a variation diagram designed to discriminate between felsic and mafic provenance indicates that the older and younger rocks plot as distinctly different trends. The high Zr/Cr trend for the Patrick Brook and Nepisiguit Falls formations implies a felsic igneous source, whereas the Ti/Nb trend (at low Zr/Cr) for the Sevogle River and Slacks Lake formations suggests a mafic igneous source. This is consistent with the findings of other studies on sedimentary rocks from the Miramichi and Tetagouche groups in the Bathurst Mining Camp (Lentz *et al.* 1996; Langton 1997).

## GEOCHRONOLOGY

### Analytical methods

Four samples were collected for radiometric dating, including sample O/1h-677 from the Stony Brook Porphyry, sample O/1b-25 from the Clearwater Stream Formation, sample O/1f-110 from the Sevogle River Formation, and sample O/8a-3934 from the Flat Landing Brook Formation. Except for the latter, the samples are located to the south of the Moose Lake–Tomogonops Fault, and dating was carried out to compare the age of igneous activity and correlate felsic volcanic units between the southern and northern parts of the Bathurst Mining Camp. Analytical procedures for U–Pb isotope dilution analysis are summarized in Parrish *et al.* (1987). All of the multigrain zircon fractions were air abraded following the method of Krogh (1982). Treatment of analytical errors is outlined in Roddick (1987) and regression

analysis is modified from York (1969). Analytical data are presented in Table 6 and in Figure 9. All quoted age uncertainties are at the 2s level. Lithogeochemical analyses of O/1h-677 and O/1b-25 appear in Appendix 1, and of O/8a-3934 in Wilson (1993b). No chemical analysis is available for O/1f-110; however, sample O/1f-101, 500 m to the northeast (see analysis in Appendix 1), is petrographically very similar.

### ***U–Pb results***

**Feldspar porphyry (O/1h-677—Stony Brook Porphyry):** The Stony Brook Porphyry intrudes the Patrick Brook Formation (upper part of the Miramichi Group) in the eastern part of the survey area, just south of the Mountain Brook Fault. Sample O/1h-677 is a dark greenish grey, weakly foliated porphyritic felsic rock containing 20% euhedral to subhedral alkali feldspar, 10% subhedral plagioclase, 5% biotite and minor calcite in a microfelsitic matrix (65%, 0.10 mm). Accessory minerals are apatite, zircon and titanite. The outcrop is located on a logging road 800 m north of the Northwest Miramichi River and 1200 m southwest of Mountain Brook (site #1, Figure 2).

The zircon population consists of clear, colourless, equant to prismatic crystals with common rod-shaped inclusions. The six analysed zircon fractions form a scattered array interpreted as resulting from a mixture of inherited and magmatic zircons (Figure 9a). The nearly concordant fraction D yields a  $^{206}\text{Pb}/^{238}\text{U}$  age of  $471.5 \pm 0.8$  Ma. Fractions B and C are more discordant but give similar ca. 471–472 Ma  $^{206}\text{Pb}/^{238}\text{U}$  ages as fraction D. Regressing fraction D with fractions A, E, and F separately, yields lower intercept ages of 470–471 Ma and upper intercept ages between ca. 1245 to 1925 Ma, indicating a wide range of ages of the inherited zircons. An interpreted age of  $471 \pm 2$  Ma is based on the consistency of the  $^{206}\text{Pb}/^{238}\text{U}$  ages for the least discordant fractions and the regression results.

**Rhyolitic crystal tuff (O/8a-3934—Flat Landing Brook Formation):** Sample O/8a-3934 is a light grey, quartz–feldspar-phyric, fine-grained crystal tuff collected from an outcrop 400 m north of the northern boundary of the survey area (site #2, Figure 2). The crystal tuff occurs in relatively thin beds overlain and underlain by tholeiitic basalt; both felsic and mafic rocks were formerly assigned to a single unit (Boucher Brook Formation of Wilson 1993b, now referred to as the Little River Formation). Isotopic dating was carried out to determine whether the crystal tuff and host basalt, which contains no interbedded sedimentary rocks, should be assigned to the Flat Landing Brook Formation or Little River Formation. Although no thin section is available from the dated outcrop, several other samples of this tuff unit have been examined petrographically. They typically contain 10% angular phenocrasts and anhedral to subhedral, locally embayed phenocrysts of quartz (up to 1 mm); 10–20% anhedral to euhedral alkali feldspar (up to 3 mm) or minor plagioclase (up to 1 mm); 10–30% muscovite, 0–15% chlorite and 0–10% calcite, in a very fine-grained, schistose, felsitic matrix (50–55%, 0.01–0.10 mm). Accessory minerals include zircon, titanite and local apatite. Some samples have more dacitic compositions and contain more chlorite and titanite.

Zircons recovered from sample O/8a-3934 resemble those from sample O/1h-677. Obvious cores were visible in a few grains. Five zircon fractions were analysed from the crystal tuff (Figure 9b). Three fractions (C, D, and E) plot as overlapping, near-concordant ellipses and yield similar  $^{206}\text{Pb}/^{238}\text{U}$  and  $^{207}\text{Pb}/^{235}\text{U}$  ages averaging  $465.0 \pm 0.3$  Ma. Fraction B plots just below concordia at 457 Ma. The fifth fraction, A, is more discordant, possibly owing to both inheritance and Pb loss. Fitting a regression line through the origin and the four most co-linear analyses (B, C, D, and E) gives an age of  $466 \pm 2$  Ma, within error of the U–Pb ages for fractions C, D, and E. The consistency of these results indicates an age of 465 Ma for the crystal tuff with an estimated error of  $\pm 2/-1$  Ma.

Table 6. U-Pb Zircon Analytical Data.

Frac- tion <sup>a</sup>	Wt. <sup>b</sup> µg	U ppm	Pb <sup>c</sup> ppm	<sup>206</sup> Pb/ <sup>234</sup> Th	Pb <sup>d</sup> pg	<sup>206</sup> Pb/ <sup>208</sup> Pb	Radiogenic ratios (±1σ, %) <sup>e</sup>			Ages (Ma, ±2 σ) <sup>f</sup>		
							<sup>206</sup> Pb/ <sup>238</sup> U	<sup>207</sup> Pb/ <sup>235</sup> U	<sup>207</sup> Pb/ <sup>206</sup> Pb	<sup>206</sup> Pb/ <sup>238</sup> U	<sup>207</sup> Pb/ <sup>235</sup> U	<sup>207</sup> Pb/ <sup>206</sup> Pb
Feldspar porphyry: O/1h-677 (Stony Brook Porphyry)												
A	15	266.3	22.71	657	32	0.191	0.07937±0.13	0.6382±0.30	0.05831±0.24	492.4±1.2	501.2±2.3	541.4±10
B	12	243.9	19.61	1693	8	0.177	0.07571±0.09	0.5973±0.15	0.05722±0.11	470.5±0.9	475.5±1.2	500.0±4.9
C	17	306.6	24.91	375	70	0.185	0.07601±0.16	0.5984±0.47	0.05710±0.38	472.2±1.4	476.2±3.5	495.3±17
D	20	262.3	21.48	4991	5	0.198	0.07588±0.09	0.5917±0.11	0.05656±0.06	471.5±0.8	472.0±0.8	474.5±2.5
E	10	312.3	26.35	3242	5	0.202	0.07778±0.09	0.6271±0.12	0.05848±0.08	482.8±0.9	494.3±0.9	547.7±3.3
F	16	292.7	26.23	3660	7	0.180	0.08385±0.09	0.7195±0.11	0.06224±0.05	519.0±0.9	550.4±0.9	682.3±2.3
Quartz-feldspar-phyrlic crystal tuff: O/8a-3934 (Flat Landing Brook Formation)												
A	8	613.3	49.10	1957	12	0.211	0.07336±0.09	0.5729±0.16	0.05664±0.12	456.3±0.8	459.9±1.2	477.7±5.2
B	7	674.0	53.95	1469	16	0.211	0.07341±0.11	0.5688±0.19	0.05620±0.13	456.6±0.9	457.2±1.4	460.2±6.0
C	11	502.8	40.05	3551	8	0.183	0.07469±0.09	0.5804±0.12	0.05636±0.07	464.4±0.8	464.8±0.9	466.7±2.9
D	41	703.6	57.13	16040	8	0.207	0.07471±0.09	0.5803±0.10	0.05633±0.04	464.5±0.8	464.6±0.8	465.6±1.6
E	26	395.5	32.24	7783	6	0.211	0.07470±0.10	0.5810±0.11	0.05641±0.06	464.4±0.9	465.1±0.8	468.7±2.4
Plagioclase-phyrlic dacitic tuff: O/1b-25 (Clearwater Stream Formation)												
A	10	252.1	21.32	2562	5	0.235	0.07603±0.10	0.5945±0.13	0.05671±0.09	472.4±0.9	473.7±1.0	480.1±3.9
B	12	208.9	18.11	2691	5	0.251	0.07699±0.12	0.6021±0.15	0.05672±0.10	478.1±1.1	478.6±1.1	480.7±4.6
C	8	115.1	9.88	1209	4	0.230	0.07757±0.35	0.6051±0.45	0.05658±0.38	481.6±3.2	480.5±3.5	475.0±17
D	5	559.8	45.61	750	18	0.202	0.07523±0.11	0.5893±0.28	0.05681±0.23	467.6±1.0	470.4±2.1	484.0±10
Alkali feldspar-phyrlic rhyolite: O/1f-110 (Sevogle River Formation)												
A1	8	77.4	6.29	774	4	0.197	0.07542±0.21	0.5791±0.42	0.05569±0.36	468.7±1.9	463.9±3.2	440.0±16
A3	25	139.5	11.80	2093	8	0.257	0.07478±0.10	0.5848±0.15	0.05672±0.10	464.9±0.9	467.5±1.1	480.7±4.6
A4	19	165.0	14.50	1138	13	0.331	0.07353±0.10	0.5748±0.22	0.05670±0.19	457.4±0.9	461.1±1.7	479.7±8.3
A5	23	184.5	14.65	1004	20	0.174	0.07498±0.09	0.5839±0.19	0.05648±0.13	466.1±0.8	467.0±1.4	471.4±5.9
B1	10	141.7	13.82	1286	6	0.170	0.09145±0.12	0.8765±0.29	0.06952±0.25	564.1±1.3	639.1±2.7	914.1±10

## Notes:

<sup>a</sup>All zircon fractions were strongly abraded.<sup>b</sup>Error on weight is ± 1 µg.<sup>c</sup>Radiogenic Pb.<sup>d</sup>Measured ratio corrected for spike and Pb fractionation of 0.09±0.03%/AMU.<sup>e</sup>Total common Pb on analysis corrected for fractionation and spike.<sup>f</sup>Radiogenic Pb.<sup>g</sup>Corrected for blank Pb and U and common Pb (Stacey-Kramers model Pb composition equivalent to the <sup>207</sup>Pb/<sup>206</sup>Pb age).<sup>h</sup>Corrected for blank and common Pb.

**Dacitic tuff (O/1b-25—Clearwater Stream Formation):** Sample O/1b-25 is a strongly foliated, upper greenschist facies, porphyritic felsic volcanic rock. The dated sample contains 20% subhedral to anhedral plagioclase, 10% chlorite, 5% muscovite, minor epidote and accessory apatite in a fine-grained, schistose, recrystallized quartzofeldspathic matrix (70%, 0.1–0.5 mm). The outcrop is located on a logging road 1 km west of Clearwater Stream and 2.4 km northwest of the decline at the Chester massive sulphide deposit (site #3, Figure 2). This location is 300 m from the contact with underlying sedimentary rocks of the Patrick Brook Formation (i.e., the upper part of the Miramichi Group), and 200 m from the overlying Sevogle River Formation; however, because of strong regional deformation and metamorphism, the nature of the contacts could not be ascertained.

A small number of fair quality zircons were recovered from this sample; four zircon fractions were analyzed. All of the zircons in this sample contained abundant, mostly fluid inclusions and minor fractures. Analyzed fractions include stubby prisms (fractions A and B), prismatic crystals with aspect ratios of 2.5–3:1 (fraction C), and stubby prismatic grains with somewhat rounded facets (fraction D; Figure 9c). The <sup>206</sup>Pb/<sup>238</sup>U age

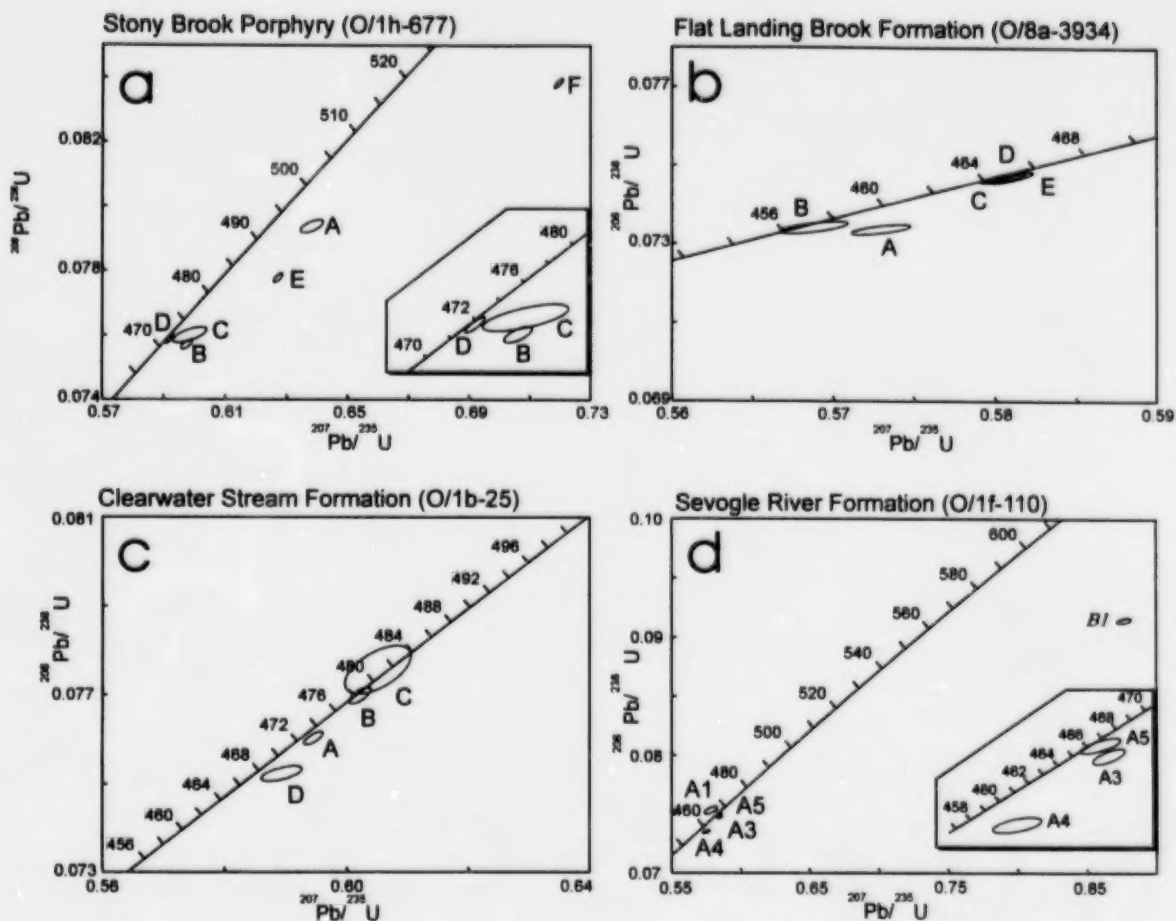


Figure 9. U-Pb concordia diagrams for samples of felsic igneous rocks from the Big Bald Mountain area. (a) Sample O/1h-677—Stony Brook Porphyry; (b) sample O/8a-3934—Flat Landing Brook Formation; (c) sample O/1b-25—Clearwater Stream Formation; (d) sample O/1f-110—Sevogle River Formation.

of concordant fraction B is  $478.1 \pm 1.1$  Ma. Although fraction C is a poor analysis, the age of this fraction overlaps and is in agreement with the age of fraction B. Fractions A and D are interpreted to have undergone a minor amount of Pb loss. The upper intercept of a linear regression through the origin and the three best quality analyses (A, B, and D) is  $480 \pm 3$  Ma (MSWD = 0.26). The best interpretation for the age of the rock is taken to be  $478 \pm 3/-1$  Ma.

**Porphyritic rhyolite (O/1f-110—Sevogle River Formation):** Sample O/1f-110 is a pale green foliated rhyolite containing 15% pink, subhedral, alkali-feldspar phenocrysts (0.5–1.8 mm), <5% plagioclase (0.4–1.0 mm), 5–10% muscovite, minor epidote and accessory Fe–Ti oxides in a very fine-grained, schistose, microfelsitic matrix (75%, 0.02–0.2 mm). The sample was collected on a logging road 400 m northeast of Clearwater Stream and 2.6 km west-northwest of Clearwater Lake (site #4, Figure 2), about 400 m from the contact with overlying basalts of the Slacks Lake Formation.

Zircons recovered from this rock include sharply faceted, elongate prismatic grains with abundant, mostly fluid, rod-shaped inclusions and some fractures (fractions A1, A3, A4, and A5) and very clear, colourless, equant, multifaceted grains (fraction B1; Figure 9d). The dominant morphologies in the sample are the elongate, inclusion-rich, prismatic grains. The  $^{206}\text{Pb}/^{238}\text{U}$  age of analysis A5, which is nearly concordant, is  $466.1 \pm 0.9$  Ma. The  $^{206}\text{Pb}/^{238}\text{U}$  ages of fractions A3 and A1 are in agreement with this age ( $465 \pm 1$  Ma and  $468 \pm 2$  Ma, respectively). The best interpretation for the age of the rock is taken to be  $466 \pm 2$  Ma. Fraction A4 is interpreted to have undergone a minor amount of Pb loss. Fraction B1 contains a large inherited component of probable Proterozoic age.

## DISCUSSION

Numerous contrasts in the trace-element geochemistry of volcanic rocks in the Tetagouche and Sheephouse Brook groups can be used to infer different sources and (or) petrogenetic histories for the respective magmatic suites. For example, felsic volcanic rocks in the Sheephouse Brook Group have higher HFSE and REE contents than those in the Tetagouche Group, as well as contrasting values of key petrogenetic indicators such as Zr/Y, Nb/Y, Nb/Ta and Zr/Hf. Changes in the latter are generally not related to fractionation processes, suggesting a dissimilarity in source composition and possibly in degree of partial melting. In the Tetagouche Group, trace-element systematics of the Nepisiguit Falls and Flat Landing Brook formations have been explained as a result of a two-stage partial melting process, involving first stage melting at relatively low temperature and high water fugacity to produce the HFSE- and REE-poor Nepisiguit Falls melts, and second stage melting at higher temperatures and lower water fugacities to produce the more HFSE- and REE-rich melts of the overlying Flat Landing Brook Formation (Lentz and Goodfellow 1992; Lentz 1996). However, in the Sheephouse Brook Group, the Clearwater Stream Formation contains higher trace-element abundances than younger rhyolites of the Sevogle River Formation and, indeed, than any other unit in the Bathurst Mining Camp. It seems likely, therefore, that the Clearwater Stream magmas were generated as small fraction partial melts, and that the crustal source probably had a somewhat different chemical signature than that which generated the Tetagouche magmas.

Important differences also exist between mafic volcanic rocks in the Tetagouche and Sheephouse Brook groups. In the Tetagouche Group, Forty Mile Brook tholeiites in the Flat Landing Brook Formation are overlain by Brunswick alkalic basalts of the Little River Formation; basalts of both units are typically pillowed. In contrast, alkalic and sub-alkalic basalts in the Sheephouse Brook Group appear to be interbedded, and no pillows have been observed. Subalkalic basalts in the Sheephouse Brook Group have many characteristics of continental tholeiites, e.g.,  $\text{Zr/Y} > 5$ , elevated light REE, low Cr and Ni, and the within-plate tholeiitic setting on a Nb–Zr–Y tectonic discrimination diagram (Figure 7b). The Forty Mile Brook tholeiites, on the other hand, have flat REE profiles,  $\text{Zr/Y} < 5$ , high Cr and Ni, and MORB-like affinities on a Nb–Zr–Y diagram (Figure 7b).

Van Staal *et al.* (1991) have interpreted the Forty Mile Brook tholeiites as uncontaminated continental tholeiites generated by 10% mantle melting and emplaced directly at the surface with little pooling at the base of the crust; a true mid-ocean-ridge setting is unlikely because of the abundance of underlying felsic volcanic (Nepisiguit Falls and Flat Landing Brook formations) and sedimentary rocks (Miramichi Group). In support of this, the Forty Mile Brook tholeiites show little evidence of Th enrichment, which is indicative of crustal contamination, on a Ta/Yb vs. Th/Yb discrimination diagram (Figure 10). The Slacks Lake tholeiitic basalts, on the other hand, display a prominent vertical vector into the active continental margin field as a result of crustal assimilation or contribution from a subducting slab. Original Ta/Yb and Th/Yb

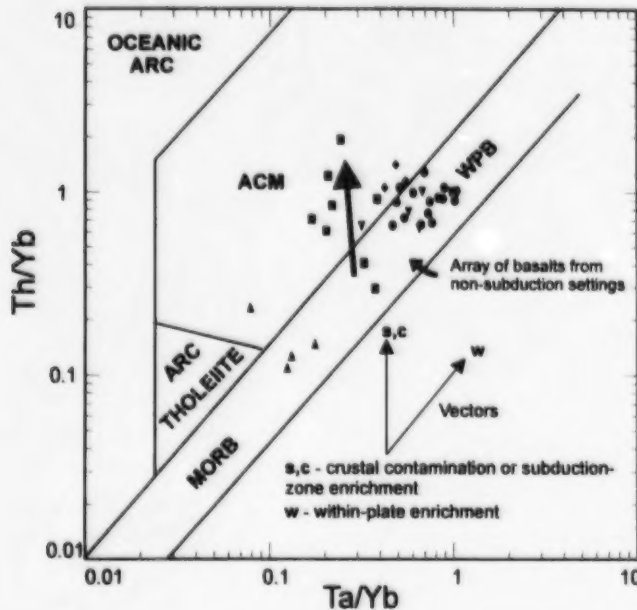


Figure 10. Ta/Yb vs. Th/Yb discrimination diagram (Pearce 1982) for mafic volcanic rocks from the Big Bald Mountain area. Abbreviations: MORB—mid-ocean-ridge basalt; WPB—within-plate basalt; ACM—active continental margin basalt. Heavy black arrow indicates Th-enrichment trend in Slacks Lake tholeiitic basalts. See text for explanation of vectors. Symbols as in Figure 7.

ratios for the Slacks Lake tholeiites, i.e., those within the so-called “mantle array” (Figure 10), are higher than those of the Forty Mile Brook tholeiites, suggesting different source chemistry. Furthermore, average Zr/Nb varies from 13.0 in the Slacks Lake tholeiites to 14.2 in the Forty Mile Brook Member, which can be explained by either different mantle sources or degrees of partial melting. The variation in these ratios is mirrored by alkalic basalts within the Sheephouse Brook and Tetagouche groups: average Zr/Nb is 7.2 in Slacks Lake alkalic basalts, whereas in the Brunswick Mines alkalic basalts average Zr/Nb is 8.0. Trachytes and comendites in the Slacks Lake Formation are interpreted as differentiates of spatially related alkalic basalts and trachyandesites (cf. van Staal and Fyffe 1991).

The recently obtained U–Pb dates provide constraints on interpretations of the geological evolution of the Big Bald Mountain area, and allow correlations to be made with other parts of the Bathurst Mining Camp. The new age of  $466 \pm 2$  Ma for the Sevogle River Formation permits correlation with the Flat Landing Brook Formation, dated at  $466 \pm 5$ ,  $465 \pm 2/-1$ , and  $466 \pm 2$  Ma (Sullivan and van Staal 1990, 1996; and Rogers *et al.* 1997, respectively). However, the new  $478 \pm 3/-1$  Ma (lower to middle Arenigian) date for the Clearwater Stream Formation suggests that it is not directly correlative with the Nepisiguit Falls Formation ( $471 \pm 3$  and  $469 \pm 2$  Ma, Sullivan and van Staal 1996;  $473 \pm 5/-3$  Ma, Rogers *et al.* 1997), but may instead be related to the earliest stages of arc-rifting during opening of the (Iapetus II) back-arc basin. The large discrepancy in the indicated ages of the Sevogle River and Clearwater Stream formations implies that the contact between the two may be either tectonic or unconformable; intense deformation throughout this area will likely preclude easy resolution of this problem.

The  $465 \pm 2/-1$  Ma isotopic age obtained on crystal tuff from near the stratigraphic top of the Flat Landing Brook Formation is similar in age to other volcanic rocks from this unit, and confirms that the basalts hosting the tuff beds are best assigned to the Forty Mile Brook Member, consistent with their subalkaline compositions. Local occurrences of red-maroon cherty ironstone in the northeastern part of the survey area, indicating a hiatus in volcanic activity, are provisionally assumed to identify the contact between Forty Mile Brook tholeiite and overlying Little River alkalic basalts. It is also clear that the Flat Landing Brook Formation contains felsic rocks with chemical traits transitional to the peralkaline compositions more typical of the overlying Little River Formation. The Stony Brook Porphyry in the eastern part of the survey area is chemically and mineralogically akin to the Clearwater Lake Porphyry in the central part, and the two were originally grouped as one unit (Wilson and Fyffe 1996). However, the newly obtained U-Pb zircon date of  $471 \pm 2$  Ma for the Stony Brook Porphyry reveals a significant difference in age, requiring a separation to be made, as the Clearwater Lake Porphyry clearly intrudes the much younger Sevogle River Formation ( $466 \pm 2$  Ma). Therefore, the Stony Brook Porphyry, although chemically more evolved, may instead be contemporaneous with the Squirrel Falls Porphyry.

## CONCLUSIONS

1. Petrographic and geochemical diversity in volcanic rocks from the Sheephouse Brook and Tetagouche groups support tectonostratigraphic models that invoke emplacement in separate basins from separate magma sources (Rogers and van Staal 1996; Rogers 1994; McCutcheon *et al.* 1997; Wilson *et al.* 1998). Significant differences are documented in the trace-element systematics of felsic and mafic volcanic rocks in the respective groups, e.g., higher HFSE and REE, and contrasting trace-element ratios in felsic volcanic rocks of the Sheephouse Brook Group, and chemical signatures in mafic volcanic rock suites that suggest slightly different source compositions, degrees of partial melting and/or crustal residence time. Contrasting paleogeographic/tectonic settings may also explain the different structural styles evident in rocks on opposite sides of the Moose Lake-Tomogonops and Mountain Brook faults (Wilson and Fyffe 1996).
2. New U-Pb radiometric dates obtained from felsic volcanic rocks of the Sheephouse Brook Group point out a substantial difference in the ages of the Clearwater Stream ( $478 \pm 3/-1$  Ma) and Sevogle River ( $466 \pm 2$  Ma) formations, suggesting that a depositional hiatus or tectonic break may exist between these two units. The age of the Sevogle River Formation coincides with that of the Flat Landing Brook Formation. A new date ( $465 \pm 2/-1$  Ma) obtained from crystal tuff interbedded with tholeiitic basalt of the Forty Mile Brook Member, near the top of the Flat Landing Brook Formation, is consistent with previously reported ages for this unit. The Stony Brook Porphyry, which intrudes the Patrick Brook Formation, is considerably older ( $471 \pm 2$  Ma) than chemically and petrographically similar rocks of the Clearwater Lake Porphyry, which intrudes the Sevogle River Formation.
3. Chemical similarities can be documented between Sheephouse Brook felsic volcanic rocks and spatially related felsic intrusive rocks; in particular, the Clearwater Stream Formation resembles the Squirrel Falls Porphyry, and the Sevogle River Formation resembles the Clearwater Lake Porphyry, suggesting that the porphyries are the subvolcanic counterparts of the intrusive units. Minor geochemical disparities between the volcanic and plutonic rocks may be related to continued fractionation within the magma chamber after the volcanic rocks were erupted.

4. Both the Sevgle River and Flat Landing Brook formations contain some felsic volcanic rocks with compositions transitional between calc-alkalic rhyolites that are typical of these units, and overlying peralkaline felsic rocks of the Slacks Lake and Little River formations, respectively.
5. Older sedimentary rocks from the Patrick Brook and Nepisiguit Falls formations display an increasing Zr/Cr trend at relatively constant V/Nb, suggesting a felsic igneous source, whereas younger sedimentary rocks of the Sevgle River and Slacks Lake formations feature an increasing V/Nb trend at more or less constant Zr/Cr, implying a mafic provenance.

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## APPENDIX 1: LITHOGEOCHEMICAL ANALYSES

(Major oxides are in weight %, trace and rare-earth elements in parts per million)

## KEY TO ABBREVIATIONS

**Formation**

CW	Clearwater Stream Formation
SR	Sevogle River Formation
SK	Slacks Lake Formation
NF	Nepisiguit Falls Formation
NFLF	Nepisiguit Falls Formation (Little Falls Member)
FL	Flat Landing Brook Formation
FLFM	Flat Landing Brook Formation (Forty Mile Brook Member)
LRBM	Little River Formation (Brunswick Mines Member)
PB	Patrick Brook Formation
KB	Knights Brook Formation
SQF	Squirrel Falls Porphyry
STB	Stony Brook Porphyry
CLW	Clearwater Lake Porphyry
BBK	Barracks Brook Granite
MEB	Meridian Brook Granite
MUS	Mullin Stream Lake Granite
CBK	Clarks Brook Granite
Ofi	Quartz-feldspar porphyry dyke
Omi	Miscellaneous mafic intrusive rocks

**Rock Type**

FL	Felsic lava
FT	Felsic tuff
FI	Felsic intrusion
ML	Mafic lava
MT	Mafic tuff
MI	Mafic intrusion
Sh	Shale
Sl	Siltstone
W	Wacke
Ex	Exhalite (ironstone)
(f)	Feldspar-phyric
(qf)	Quartz- and feldspar-phyric
(alt)	Hydrothermally altered

## Appendix 1. Lithochemical analyses.

FIELD # FORMATION ROCK TYPE	O/1B-02a SQF FI (f)	O/1B-04 MUS FI	O/1B-05 MUS FI	O/1B-06 MUS FI	O/1B-07a SQF FI (f)	O/1B-15 CW FT	O/1B-16 SR FL (alt)	O/1B-17 SR FL	O/1B-20 SK ML	O/1B-21 SR FL	O/1B-22 SR FL	O/1B-23 SK ML
SiO <sub>2</sub>	68.85	75.41	71.76	68.94	69.56	71.34	69.85	70.33	57.35	70.56	68.02	54.35
TiO <sub>2</sub>	0.76	0.22	0.34	0.56	0.57	0.34	0.32	0.35	1.31	0.36	0.41	1.23
Al <sub>2</sub> O <sub>3</sub>	14.49	13.31	14.51	14.57	14.40	11.61	13.82	14.25	15.12	14.24	15.04	13.84
Fe <sub>2</sub> O <sub>3</sub>	5.39	1.50	2.99	4.79	4.39	3.01	2.11	2.35	14.25	3.18	2.93	14.54
MnO	0.17	0.03	0.04	0.05	0.04	0.15	0.01	0.04	0.21	0.04	0.03	0.21
MgO	1.15	0.20	0.63	1.22	1.27	1.74	0.11	0.90	1.84	0.93	0.62	5.77
CaO	1.20	0.14	0.46	2.41	2.80	1.98	0.02	0.13	1.39	0.17	0.06	2.17
Na <sub>2</sub> O	3.34	3.78	4.06	3.55	3.54	1.48	0.26	1.02	6.53	3.44	1.66	2.61
K <sub>2</sub> O	3.10	4.10	3.54	2.08	1.25	4.91	11.16	8.21	1.12	4.99	9.45	1.12
P <sub>2</sub> O <sub>5</sub>	0.22	0.06	0.13	0.13	0.14	0.11	0.08	0.14	0.49	0.18	0.11	0.30
LOI	1.40	1.00	0.90	1.60	1.50	3.10	0.80	1.40	2.00	0.90	0.90	5.20
Cr	34	27	20	37	35	17	17	14	9	22	14	8
Ni	13	3	3	12	11	3	5	3	7	3	3	3
Co	8.7	1.3	3.8	6.3	8.1	1.0	0.9	2.3	6.5	2.2	1.7	4.5
Sc	14.7	13.1	8.0	13.2	13.0	17.6	21.1	7.0	30.6	12.3	9.3	30.1
V	74	10	33	71	67	6	5	20	3	18	17	3
Cu	7	3	3	5	3	7	6	5	32	3	3	5
Pb	10	17	19	17	5	13	30	46	10	20	16	16
Zn	67	38	48	43	36	79	27	74	249	30	55	236
Rb	111	94	87	71	43	128	188	226	53	153	290	39
Ba	579	578	1042	658	300	481	1378	563	230	465	759	469
Sr	117	67	107	319	311	41	58	22	136	31	23	141
Ga	20.0	17.0	18.0	17.0	15.0	15.0	13.0	17.0	25.0	18.0	20.0	33.0
Ta	1.23	1.24	0.97	0.96	0.92	1.33	1.58	1.09	4.18	1.37	1.34	3.93
Nb	17.0	16.0	11.0	13.0	13.0	19.0	22.0	14.0	53.0	17.0	17.0	57.0
Hf	8.74	6.90	5.86	6.01	5.95	8.50	8.53	8.30	14.17	6.67	9.60	13.08
Zr	305	205	188	199	192	315	323	295	667	238	365	592
Y	55.0	55.0	41.0	29.0	27.0	47.0	61.0	52.0	90.0	48.0	48.0	74.0
Th	17.83	17.05	15.91	13.40	12.41	15.40	17.74	26.76	8.69	16.57	24.70	7.87
U	3.60	3.37	3.60	2.97	3.23	3.85	5.31	5.96	1.76	5.36	5.27	1.79
La	53.77	74.91	56.06	31.47	26.45	45.56	54.03	55.04	64.67	16.08	54.55	56.13
Ce	112.04	119.54	101.22	67.68	59.22	101.87	121.47	120.11	135.26	38.76	115.47	121.59
Nd	56.50	61.30	51.02	30.21	25.26	48.74	52.97	55.33	73.38	15.08	50.84	64.20
Sm	10.81	12.70	9.93	5.83	4.55	9.80	10.39	11.15	16.88	4.79	10.58	15.02
Eu	1.67	1.57	1.49	1.29	1.18	1.54	1.56	0.90	5.03	0.76	1.10	4.82
Tb	1.66	1.75	1.36	0.78	0.72	1.53	1.88	1.68	2.91	1.28	1.58	2.43
Yb	4.97	5.13	3.81	3.03	3.06	4.96	5.07	4.88	7.62	4.80	5.08	7.48
Lu	0.69	0.73	0.54	0.45	0.45	0.72	0.72	0.70	1.08	0.68	0.74	1.04

(Appendix 1 continued)

FIELD # FORMATION ROCK TYPE	O/1B-24 SR FL (alt)	O/1B-25 CW FT	O/1B-26 SR FL (alt)	O/1B-27a SK ML	O/1B-27b SR FL	O/1B-29 SR FL (alt)	O/1B-31 SR FL (alt)	O/1B-32 SR FL	O/1B-34 CW FT	O/1B-35 CW FT (alt)	O/1B-36 CW FT (alt)	O/1B-37 CW FT (alt)
SiO <sub>2</sub>	67.93	63.24	76.95	46.57	69.00	71.85	78.59	65.23	63.89	72.74	78.62	78.56
TiO <sub>2</sub>	0.25	0.88	0.20	2.11	0.66	0.25	0.19	0.35	0.40	0.20	0.11	0.21
Al <sub>2</sub> O <sub>3</sub>	10.36	16.48	11.55	16.77	15.12	13.57	10.96	14.28	17.38	7.94	5.36	10.03
Fe <sub>2</sub> O <sub>3</sub>	11.36	6.25	1.56	12.16	2.14	2.19	2.09	2.63	4.20	11.15	10.70	2.06
MnO	0.09	0.05	0.02	0.17	0.02	0.03	0.03	0.13	0.06	0.20	0.10	0.02
MgO	2.62	3.44	0.34	5.13	0.43	0.54	0.66	0.82	1.73	5.38	2.95	0.25
CaO	0.00	0.96	0.05	5.68	0.10	0.00	0.00	3.19	0.28	0.00	0.00	0.05
Na <sub>2</sub> O	3.54	4.43	1.20	5.88	1.48	0.18	0.04	1.72	0.90	0.00	0.04	0.12
K <sub>2</sub> O	0.15	1.47	6.68	0.45	8.36	8.94	6.12	8.73	6.38	0.06	0.09	6.74
P <sub>2</sub> O <sub>5</sub>	0.05	0.22	0.05	0.28	0.15	0.03	0.03	0.10	0.27	0.04	0.03	0.02
LOI	4.00	3.70	0.40	6.20	0.80	1.10	1.60	2.50	3.1	3.40	3.00	1.20
Cr	23	29	15	306	20	13	17	21	22	26	23	14
Ni	5	8	3	144	5	3	5	3	3	3	3	3
Co	9.5	9.3	0.5	38.9	0.6	0.7	0.7	2.8	3.4	8.5	44.0	0.9
Sc	17.0	17.5	16.4	31.0	9.6	23.7	15.1	8.3	24.5	14.7	8.2	18.0
V	11	101	3	319	48	3	3	18	21	7	5	8
Cu	960	13	3	34	3	31	37	6		7	1228	30
Pb	43	18	22	11	17	29	10	34	17	5	11	305
Zn	1017	86	76	89	45	517	46	807	92	102	126	289
Rb	5	57	149	10	201	241	176	204	277	3	3	196
Ba	16	569	728	647	1440	1101	1376	705	1132	3	3	548
Sr	12	89	54	387	55	30	47	67	32	3	3	16
Ga	20.0	21.0	15.0	20.0	18.0	23.0	15.0	15.0	26.4	13.0	14.0	21.0
Ta	1.22	1.33	1.41	1.21	1.43	1.76	1.75	1.29	1.99	0.92	0.70	1.23
Nb	15.0	20.0	19.0	21.0	19.0	24.0	20.0	14.0	23.3	13.0	10.0	17.0
Hf	6.23	9.42	6.91	3.49	8.60	8.47	6.71	8.93	7.95	5.32	3.76	6.68
Zr	238	352	228	155	322	296	233	326	261	192	118	223
Y	67.0	46.0	51.0	29.0	48.0	55.0	55.0	52.0	78.2	32.0	26.0	42.0
Th	14.72	20.18	18.54	1.70	18.30	21.42	13.92	23.94	25.64	11.42	8.26	15.91
U	6.15	3.59	3.77	0.71	5.42	4.65	5.43	6.10	6.41	2.76	1.85	3.11
La	33.50	40.95	52.99	17.07	28.61	28.26	12.29	50.58	62.08	30.80	25.36	41.36
Ce	75.87	79.41	113.89	37.93	69.40	59.87	27.27	110.94	134.96	67.72	51.11	89.47
Nd	32.05	38.69	53.99	20.12	27.21	28.10	11.08	53.52	62.37	35.99	23.94	42.44
Sm	8.31	7.42	10.85	4.88	6.02	7.26	4.26	10.12	14.86	6.43	4.94	7.43
Eu	0.85	0.94	1.24	1.79	0.86	0.94	0.52	0.98	1.17	0.46	0.45	1.17
Tb	1.54	1.13	1.61	0.89	1.25	1.52	1.49	1.64	2.69	1.03	0.82	1.17
Yb	6.71	4.91	4.96	2.60	4.53	6.20	5.97	5.51	7.68	3.60	2.75	4.93
Lu	1.16	0.71	0.72	0.32	0.66	0.90	0.84	0.75	1.05	0.50	0.39	0.70

(Appendix 1 continued)

FIELD # FORMATION ROCK TYPE	O/1B-38 CW FT (alt)	O/1B-39 SR FL (alt)	O/1B-41 CW FT	O/1B-43 Omi MI	O/1B-44 BBK FI	O/1B-53 CW FT	O/1B-54 CW FT	O/1B-T2-1 SR FL (alt)	O/1B-T2-2 SR FL	O/1B-T2-3 SR FL	O/1B-T2-4 SR FL	O/1B-T2-5 SR FL
SiO <sub>2</sub>	74.94	71.83	57.61	46.40	75.28	60.06	72.50	65.70	73.90	66.50	62.30	68.50
TiO <sub>2</sub>	0.30	0.25	0.80	3.04	0.18	0.88	0.41	0.32	0.23	0.37	0.43	0.39
Al <sub>2</sub> O <sub>3</sub>	12.72	14.47	16.64	13.21	13.02	16.19	13.03	17.40	13.00	14.10	18.60	15.00
Fe <sub>2</sub> O <sub>3</sub>	3.75	1.85	6.73	12.26	2.23	7.06	3.68	3.35	2.61	2.59	2.30	2.99
MnO	0.05	0.03	0.07	0.22	0.03	0.08	0.09	0.05	0.04	0.19	0.04	0.06
MgO	1.24	0.69	4.87	5.63	0.61	4.24	0.90	2.04	1.36	1.39	2.50	3.18
CaO	0.00	0.00	2.98	8.41	0.38	2.24	0.19	0.01	0.03	2.57	0.87	0.53
Na <sub>2</sub> O	3.12	2.11	2.26	2.78	4.03	2.74	1.94	0.04	2.16	0.18	2.26	1.90
K <sub>2</sub> O	2.11	7.01	2.50	0.02	2.30	2.21	3.94	7.43	4.35	8.77	6.63	4.86
P <sub>2</sub> O <sub>5</sub>	0.08	0.05	0.21	0.43	0.30	0.22	0.08	0.04	0.02	0.12	0.08	0.08
LOI	1.80	0.90	5.60	8.40	0.80	3.3	1.9					
Cr	13	9	23	192	23	35	13	1	2	7	1	1
Ni	3	3	8	50	6	12	5	5	1	2	3	3
Co	1.4	1.0	12.1	38.9	1.3	11.4	2.1	1.0	1.0	2.0	2.0	2.0
Sc	21.1	4.9	16.7	34.5	14.8	18.5	23.2	32.0	24.0	10.0	11.0	10.0
V	3	7	93	422	8	105	9	6	1	20	15	17
Cu	56	14	28	27	3							
Pb	5	14	27	95	5	17	12	111	9	20	99	21
Zn	84	47	96	134	40	86	72	222	36	32	116	54
Rb	80	192	70	3	77	74	148	323	133	227	266	213
Ba	298	632	343	3	156	555	568	513	1360	1220	935	441
Sr	31	15	171	160	54	172	26	16	42	246	78	58
Ga	19.0	23.0	21.0	19.0	20.0	21.5	18.9	26.0	18.0	21.0	23.0	17.0
Ta	1.50	2.90	1.47	1.78	1.51	1.73	1.70	1.60	1.00	0.90	1.40	1.20
Nb	19.0	37.0	20.0	22.0	17.0	17.8	19.5	19.0	22.0	11.0	20.0	15.0
Hf	8.13	9.32	10.01	4.20	4.76	9.71	9.99	12.00	7.50	10.00	13.00	11.00
Zr	285	310	361	169	136	320	344	395	340	333	412	404
Y	60.0	49.0	56.0	33.0	59.0	49.2	58.3	82.0	58.0	78.0	59.0	52.0
Th	15.36	25.73	21.89	1.47	13.33	22.20	20.49	29.00	20.00	26.00	33.00	25.00
U	4.06	5.55	4.86	0.43	7.26	4.92	4.46	9.30	6.10	7.70	10.00	7.00
La	29.34	29.59	56.87	20.54	12.03	52.06	59.59	71.80	62.00	52.70	55.50	46.60
Ce	65.55	58.73	123.27	44.13	33.19	132.71	126.21	224.00	126.00	112.00	113.00	95.90
Nd	29.26	27.82	55.16	24.92	17.23	49.97	53.18	67.60	58.90	51.80	51.10	41.80
Sm	6.81	6.20	11.47	6.17	4.91	10.62	12.40	15.00	12.70	11.70	10.90	8.80
Eu	0.85	0.65	1.75	2.26	0.29	1.64	2.08	1.80	1.51	1.46	1.06	0.89
Tb	1.55	1.36	1.75	0.90	1.39	1.83	2.15	2.30	1.80	2.00	1.60	1.40
Yb	5.47	5.24	5.14	2.98	6.80	5.09	6.54	8.30	5.90	6.60	5.50	4.80
Lu	0.76	0.75	0.73	0.40	0.99	0.71	0.92	1.31	0.93	0.97	0.82	0.72

(Appendix 1 continued)

FIELD # FORMATION ROCK TYPE	O/1B-T2-6 SR FL	O/1B-T2-7 SR FL	O/1C-01a CW FT	O/1C-01b CLW FI (f)	O/1C-04 SQF FI (f)	O/1C-05 SQF FI (f)	O/1C-07 Oml MI	O/1C-10 BBK FI	O/1C-11 BBK FI	O/1C-13 BBK FI	O/1C-14 BBK FI	O/1C-16 BBK FI
SiO <sub>2</sub>	61.50	70.00	60.05	69.10	68.48	68.20	50.91	67.78	75.78	75.26	68.44	72.79
TiO <sub>2</sub>	0.35	0.36	0.86	0.78	0.64	0.41	1.89	0.68	0.17	0.21	0.55	0.20
Al <sub>2</sub> O <sub>3</sub>	17.30	14.80	16.38	15.08	14.75	15.73	16.15	14.56	11.56	12.13	14.76	13.70
Fe <sub>2</sub> O <sub>3</sub>	3.26	3.24	7.40	3.15	5.70	2.92	11.66	4.96	1.58	2.15	3.79	2.62
MnO	0.03	0.01	0.08	0.08	0.06	0.06	0.19	0.04	0.02	0.03	0.09	0.03
MgO	2.73	2.47	4.25	0.53	1.76	1.10	5.25	1.80	0.34	0.40	0.95	0.16
CaO	2.31	1.22	2.02	2.58	0.08	0.55	8.07	0.50	0.37	0.23	0.45	0.07
Na <sub>2</sub> O	1.07	2.96	1.34	2.73	2.05	5.05	4.70	3.80	2.14	1.11	3.08	4.67
K <sub>2</sub> O	6.53	2.22	3.47	3.08	3.10	2.78	0.03	3.41	6.08	6.10	5.72	4.15
P <sub>2</sub> O <sub>5</sub>	0.07	0.08	0.22	0.20	0.13	0.33	0.23	0.17	0.28	0.19	0.14	0.02
LOI			3.6	1.6	2.5	1.5	0.70	1.6	0.5	1.0	1.2	0.5
Cr	5	3	19	22	19	8	11	35	13	12	16	7
Ni	2	2	9	3	4	9	30	14	5	4	8	7
Co	2.0	2.0	11.7	4.8	2.0	6.6	1.6	8.6	1.0	1.5	6.2	2.4
Sc	10.0	9.0	17.0	13.4	22.0	5.8	15.0	15.0	10.5	15.5	11.3	2.6
V	12	22	83	72	47	40	306	67	8	11	39	3
Cu												
Pb	50	27	10	15	0	54	21	3	24	4	7	19
Zn	69	49	92	53	47	63	98	66	30	62	42	107
Rb	253	120	142	129	152	99	7	136	118	187	193	99
Ba	677	786	662	671	502	926	125	465	433	643	608	455
Sr	108	109	240	600	43	489	306	30	45	19	30	38
Ga	23.0	21.0										
Ta	1.80	0.90	1.10	1.10	1.40	1.70	1.00	1.00	1.60	1.20	0.90	3.70
Nb	16.0	28.0	25.0	21.0	23.0	26.0	14.0	21.0	15.0	21.0	21.0	60.0
Hf	12.00	9.90	9.10	8.50	8.80	6.20	5.60	7.50	4.70	5.70	9.40	12.90
Zr	383	410	350	325	345	213	193	293	134	181	349	440
Y	63.0	52.0	58.0	46.0	46.0	18.0	31.0	46.0	51.0	65.0	50.0	61.0
Th	35.00	24.00	18.70	17.90	18.60	25.60	17.80	17.10	13.30	17.00	22.40	21.00
U	9.80	6.80	5.00	5.60	4.70	8.90	5.90	4.70	5.30	5.60	4.70	6.20
La	62.70	49.10	79.20	54.70	56.20	87.80	48.80	55.50	29.60	35.40	89.50	90.70
Ce	131.00	102.00	141.00	108.00	122.00	141.00	90.00	121.00	70.00	89.00	127.00	197.00
Nd	57.40	45.90	74.00	52.00	53.00	63.00	47.00	53.00	35.00	40.00	74.00	85.00
Sm	12.20	10.00	13.40	10.20	10.10	7.80	10.30	9.39	7.53	8.85	11.30	14.50
Eu	1.12	1.16	2.31	1.69	1.11	2.23	0.95	1.54	0.48	0.85	1.75	2.51
Tb	1.80	1.50	2.10	1.70	1.50	0.50	2.40	1.60	1.80	1.80	1.70	2.60
Yb	5.80	4.80	6.02	5.18	5.23	1.26	8.40	5.05	5.51	7.99	5.25	8.20
Lu	0.87	0.74	0.84	0.67	0.68	0.21	1.07	0.68	0.73	1.00	0.74	1.07

(Appendix 1 continued)

FIELD # FORMATION ROCK TYPE	O/1C-17 SQF FI (f)	O/1C-18 BBK FI	O/1C-19 BBK FI	O/1C-21a SQF FI (alt)	O/1C-23 SQF FI (f)	O/1C-24 SQF FI (f)	O/1C-25 SQF FI (f)	O/1D-033 BBK FI	O/1D-108 SQF FI (f)	O/1E-009 SR FL	O/1E-013 SR FL	O/1E-044 SK ML
SiO <sub>2</sub>	71.79	75.42	72.73	86.82	65.80	73.54	66.11	72.48	64.44	63.70	71.46	51.06
TiO <sub>2</sub>	0.37	0.20	0.21	0.54	0.81	0.12	0.83	0.21	0.90	0.22	0.30	1.89
Al <sub>2</sub> O <sub>3</sub>	14.22	12.27	13.82	6.68	15.28	14.78	15.62	12.39	15.19	18.35	14.05	16.15
Fe <sub>2</sub> O <sub>3</sub>	3.57	2.68	2.48	1.32	6.55	1.71	6.50	3.00	7.34	3.48	3.53	11.69
MnO	0.07	0.04	0.03	0.00	0.17	0.02	0.10	0.04	0.10	0.06	0.06	0.19
MgO	0.73	0.71	0.18	0.26	1.01	0.14	2.21	1.18	2.41	3.99	0.73	5.26
CaO	0.57	0.31	0.07	0.12	1.65	0.12	0.47	0.35	3.75	1.18	0.15	8.09
Na <sub>2</sub> O	6.11	2.46	4.62	0.05	3.77	7.17	3.44	1.41	2.76	0.77	5.01	4.73
K <sub>2</sub> O	0.73	3.23	4.38	1.94	2.78	0.77	2.03	6.71	1.23	3.77	2.11	0.30
P <sub>2</sub> O <sub>5</sub>	0.07	0.24	0.02	0.13	0.26	0.01	0.20	0.25	0.22	0.07	0.08	0.23
LOI	0.9	1.5	0.4	1.10	1.6	0.5	2.4	1.0	1.5	3.80	1.3	0.5
Cr	8	8	13	30	17	8	46	5	62	3	3	28
Ni	5	4	4	6	10	4	16	4	24	2	4	29
Co	3.2	1.3	1.9	0.9	8.3	1.1	7.3	1.4	17.5	0.8	2.8	36.6
Sc	10.6	17.0	2.5	4.9	17.0	3.3	17.0	15.5	17.0	11.6	17.0	31.3
V	24	10	11	29	67	0	79	4	122	13	9	310
Cu	0	0	0	0	13	0	8	34	109	40	24	20
Pb	27	36	62	9	76	37	92	60	53	96	74	95
Zn	33	119	93	98	94	27	94	204	46	189	116	9
Rb	263	585	584	249	1065	556	352	523	311	667	357	124
Ba	112	23	36	15	247	78	78	38	315	148	93	307
Sr												
Ga												
Ta	0.90	0.90	2.90	1.20	1.50	4.80	0.90	1.00	1.30	1.10	1.10	0.80
Nb	14.0	20.0	52.0	27.0	29.0	76.0	22.0	20.0	16.0	18.0	23.0	14.0
Hf	6.80	5.80	12.70	14.40	10.60	11.00	8.70	5.30	5.50	5.40	9.90	4.70
Zr	232	175	463	581	443	307	333	174	213	181	391	192
Y	24.0	72.0	41.0	26.0	59.0	66.0	43.0	66.0	33.0	59.0	71.0	30.0
Th	12.70	16.70	15.90	9.30	18.00	19.40	16.40	15.80	11.00	20.10	18.80	2.40
U	3.40	6.00	4.40	3.30	4.40	4.20	4.60	5.60	3.30	4.30	4.40	1.00
La	17.70	45.90	69.90	17.30	67.50	55.30	55.90	36.10	41.90	83.10	182.00	15.10
Ce	43.00	104.00	108.00	43.00	121.00	125.00	96.00	87.00	81.00	101.00	135.00	39.00
Nd	16.00	52.00	66.00	18.00	63.00	55.00	56.00	40.00	35.00	62.00	130.00	22.00
Sm	3.43	10.10	10.40	3.54	11.60	10.20	9.66	8.65	6.90	10.80	19.30	4.95
Eu	0.88	0.98	1.95	0.77	2.11	1.80	1.71	0.84	1.66	1.44	3.17	1.61
Tb	0.80	2.40	1.60	0.70	2.00	2.20	1.60	2.20	1.00	2.10	2.80	0.90
Yb	3.34	8.34	5.90	3.56	6.66	8.40	5.10	7.30	3.10	5.01	6.73	3.94
Lu	0.47	1.03	0.78	0.48	0.87	1.13	0.66	0.93	0.44	0.60	0.85	0.49

(Appendix 1 continued)

FIELD # FORMATION ROCK TYPE	O/1E-048 SK ML	O/1E-058 SK MT	O/1E-078 MEB FI	O/1E-172 MEB FI	O/1E-190 SR FL	O/1E-197 SK FL	O/1F-008 FL FL	O/1F-008 On FI (qf)	O/1F-009 FL FL	O/1F-011 NF FT	O/1F-014 NF FT	O/1F-015 SK ML
SiO <sub>2</sub>	42.99	49.49	72.20	71.40	64.01	65.59	66.53	74.78	68.12	73.04	73.70	51.57
TiO <sub>2</sub>	2.75	1.24	0.27	0.40	0.45	0.61	0.71	0.20	0.71	0.38	0.35	2.87
Al <sub>2</sub> O <sub>3</sub>	16.94	18.02	12.83	13.10	17.05	12.28	14.27	12.29	14.68	14.07	13.35	13.92
Fe <sub>2</sub> O <sub>3</sub>	13.01	10.77	6.55	4.16	2.60	8.59	5.54	1.49	5.67	3.32	2.68	16.00
MnO	0.52	0.20	0.09	0.08	0.02	0.11	0.10	0.01	0.06	0.04	0.05	0.13
MgO	7.19	4.85	1.06	0.99	0.40	0.79	2.14	0.62	2.20	1.32	0.71	3.91
CaO	11.95	6.52	0.30	1.68	0.21	0.43	1.40	0.06	0.29	0.18	0.23	3.96
Na <sub>2</sub> O	0.76	5.72	0.12	2.41	1.81	0.04	4.10	0.40	3.87	3.75	2.83	4.80
K <sub>2</sub> O	1.43	0.66	3.44	4.04	11.23	8.85	3.70	7.98	3.90	2.30	5.27	0.35
P <sub>2</sub> O <sub>5</sub>	0.40	0.16	0.27	0.09	0.15	0.07	0.15	0.09	0.15	0.11	0.10	1.28
LOI	2.0	1.9	2.6	0.9	0.90	1.2	1.80	1.20	1.20	0.8	0.90	2.70
Cr	291	24	9	10	15	10	29	5	18	19	15	3
Ni	110	31	5	7	7	3	8	3	8	5	8	3
Co	51.9	37.6	2.7	5.7	3.8	1.1	19.2	37.0	18.7		22.3	20.2
Sc	41.0	31.0	18.1	22.3	9.9	1.5	18.1	4.3	17.5	7.0	8.0	21.4
V	362	260	12	18	31	4	104	12	90	31	33	61
Cu							11	5	3		3	12
Pb	28	2085	0	67	29		23	12	5	14	17	5
Zn	98	81	52	95	39	85	65	17	72	24	20	130
Rb	64	1	155	178	227	110	120	136	149	131	132	3
Ba	79	453	432	661	1116	613	575	2954	656	617	684	114
Sr	182	171	13	120	67	42	78	61	44	53	64	176
Ga							19.0	14.0	18.0	15.0	19.0	25.0
Ta	1.20	0.80	1.10	1.50	1.40	8.60	1.15	1.68	1.28	0.70	1.31	4.08
Nb	23.0	0.0	22.0	25.0	20.0	145.0	14.0	9.0	13.0	10.0	12.0	57.0
Hf	4.80	2.10	6.40	7.90	7.00	19.90	6.36	4.16	6.48	5.00	5.53	8.01
Zr	196	82	254	305	250	931	230	118	241	154	169	347
Y	30.0	16.0	58.0	54.0	34.0	111.0	40.0	34.0	37.0	28.0	43.0	77.0
Th	1.50	1.90	18.20	16.10	18.40	10.20	12.42	14.37	12.66	14.30	17.80	3.61
U	0.60	0.50	5.80	4.00	3.00	2.00	3.22	5.68	3.73	4.20	3.48	0.93
La	16.30	11.20	44.00	59.00	47.20	110.00	39.14	16.63	24.55	8.60	39.99	46.17
Ce	42.00	29.00	108.00	120.00	100.00	240.00	79.51	34.55	74.06	54.00	86.28	104.40
Nd	23.00	16.00	52.00	54.00	41.00	112.00	32.33	13.43	21.05	9.00	38.90	66.02
Sm	5.20	3.38	10.70	11.20	8.41	22.00	7.82	4.03	5.40	2.25	7.84	14.39
Eu	1.93	1.15	1.13	2.04	1.35	5.52	1.62	0.85	1.17	0.33	1.01	5.20
Tb	1.10	0.50	1.70	1.70	1.30	4.10	1.16	0.90	1.08	0.60	1.35	2.24
Yb	3.69	2.09	7.25	6.34	4.16	13.90	3.75	3.08	3.55	3.15	3.90	5.35
Lu	0.50	0.28	0.92	0.82	0.54	1.69	0.56	0.42	0.52	0.43	0.52	0.79

(Appendix 1 continued)

FIELD # FORMATION ROCK TYPE	O/1F-018 SK FL	O/1F-019 SK ML	O/1F-022 SK ML	O/1F-025 CLW FI (f)	O/1F-028 CLW FI (f)	O/1F-029 SK FL	O/1F-031 SK FL	O/1F-032 CW FT	O/1F-034 CLW FI (f)	O/1F-037 SR FL	O/1F-039 CLW FI (f)	O/1F-040 SR FL (alt)
SiO <sub>2</sub>	72.15	45.90	41.80	72.63	63.46	66.75	67.51	58.73	66.38	71.41	73.62	59.45
TiO <sub>2</sub>	0.30	2.30	3.04	0.33	0.76	0.75	0.69	0.97	0.22	0.33	0.19	0.69
Al <sub>2</sub> O <sub>3</sub>	13.92	16.72	13.62	13.28	16.11	14.53	15.56	17.95	15.26	14.86	13.36	20.16
Fe <sub>2</sub> O <sub>3</sub>	4.42	11.69	13.47	2.56	5.18	5.31	4.04	6.16	1.73	2.62	1.41	2.51
MnO	0.03	0.19	0.21	0.04	0.05	0.09	0.05	0.04	0.07	0.05	0.02	0.02
MgO	1.14	7.22	2.66	0.69	3.15	1.26	0.51	4.39	0.77	3.72	0.45	1.13
CaO	0.01	9.38	11.24	0.18	0.77	1.08	0.20	3.32	1.01	0.48	0.25	0.23
Na <sub>2</sub> O	5.27	2.98	1.34	2.85	2.63	2.88	3.18	2.84	0.64	1.10	1.31	0.94
K <sub>2</sub> O	1.14	0.55	2.80	5.27	2.89	5.96	6.33	2.31	10.88	1.93	7.43	11.19
P <sub>2</sub> O <sub>5</sub>	0.03	0.30	0.99	0.12	0.19	0.26	0.17	0.23	0.09	0.08	0.23	0.20
LOI	1.50	0.90	8.3	1.5	3.00	0.90	2.10	3.30	1.60	3.60	1.40	2.30
Cr	3	229	3	14	24	7	5	19	3	3	6	10
Ni	3	162	5	3	12	6	3	7	3	3	6	5
Co	14.8	71.1	29.0	2.4	14.7	18.5	15.5	15.9	19.8	14.7	18.9	17.3
Sc	1.2	37.5	20.7	8.0	16.3	17.7	11.1	18.8	11.1	14.3	11.8	28.7
V	6	314	141	25	90	64	21	94	10	24	7	62
Cu	3	80			13	17	3	17	3	3	17	10
Pb	5	5	14	31	23	20	18	28	40	16	21	29
Zn	121	96	152	48	74	68	50	84	32	57	56	54
Rb	19	7	38	82	101	169	170	52	249	76	163	196
Ba	153	125	268	311	568	716	660	957	802	551	433	1616
Sr	41	237	177	102	77	86	50	230	34	278	48	99
Ga	33.0	19.0	27.1	20.3	23.0	19.0	25.0	26.0	18.0	22.0	20.0	30.0
Ta	10.96	1.22	4.30	1.08	1.71	1.68	3.32	1.76	1.95	1.81	1.82	1.91
Nb	163.0	15.0	57.5	14.4	19.0	20.0	44.0	22.0	18.0	19.0	17.0	23.0
Hf	30.35	3.50	8.83	8.29	9.76	9.39	18.06	11.47	6.34	9.66	5.15	11.07
Zr	1410	154	367	275	353	339	762	405	192	297	155	363
Y	116.0	35.0	56.5	51.9	39.0	61.0	44.0	64.0	56.0	82.0	61.0	59.0
Th	14.29	0.96	4.18	28.43	21.02	20.48	21.47	22.95	20.10	27.69	16.04	17.65
U	4.61	0.26	1.46	5.34	4.47	4.51	6.25	5.90	8.25	4.79	4.75	5.90
La	123.80	10.94	53.49	53.79	14.75	50.07	41.93	68.82	45.35	63.46	28.62	30.28
Ce	246.92	29.78	118.00	114.03	100.95	127.36	127.13	134.60	101.13	106.79	71.10	68.91
Nd	117.21	20.64	50.30	49.74	16.34	55.13	43.68	59.24	42.76	75.51	37.00	41.40
Sm	21.40	5.15	12.86	10.82	3.48	11.39	9.79	12.58	9.87	13.16	8.53	7.97
Eu	2.14	1.88	4.23	0.93	0.58	1.75	2.14	2.03	1.27	1.38	0.42	1.74
Tb	3.74	1.00	1.57	1.91	0.96	2.08	1.68	2.13	1.98	2.18	1.71	1.52
Yb	11.47	3.25	4.14	4.77	4.73	5.30	4.67	5.76	5.40	6.44	5.62	5.88
Lu	1.59	0.44	0.76	0.65	0.68	0.75	0.68	0.82	0.78	0.93	0.74	0.80

(Appendix 1 continued)

FIELD # FORMATION ROCK TYPE	O/1F-041 CLW FI (f)	O/1F-042 SK ML	O/1F-045 CLW FI (f)	O/1F-047 CLW FI (f)	O/1F-048 CW FT	O/1F-049 SK ML	O/1F-052 SK FL	O/1F-053 NF FT	O/1F-054 FL FL	O/1F-055a SK ML	O/1F-055b SK Ex	O/1F-056 SK Ex
SiO <sub>2</sub>	74.51	46.98	74.25	67.78	63.92	46.37	67.47	76.03	70.37	47.22	56.74	92.98
TiO <sub>2</sub>	0.20	2.63	0.18	0.63	0.82	2.22	0.61	0.35	0.44	3.38	0.54	0.05
Al <sub>2</sub> O <sub>3</sub>	11.87	15.47	12.82	13.41	15.76	15.10	14.80	12.62	13.77	14.07	9.79	0.82
Fe <sub>2</sub> O <sub>3</sub>	1.32	12.51	1.88	4.33	5.09	11.69	6.56	2.56	3.34	12.95	23.98	5.96
MnO	0.01	0.24	0.02	0.04	0.06	0.17	0.10	0.05	0.06	0.30	1.74	0.08
MgO	0.22	7.82	0.35	1.43	2.77	7.14	0.89	0.94	0.58	6.45	1.89	0.08
CaO	0.07	8.69	0.32	0.28	1.88	10.34	1.11	0.26	0.35	8.87	3.20	0.17
Na <sub>2</sub> O	1.62	3.75	1.91	2.62	3.64	2.52	3.81	5.11	4.83	3.15	3.24	0.12
K <sub>2</sub> O	7.72	0.43	7.26	5.92	1.58	0.17	2.43	1.75	3.70	0.31	1.26	0.22
P <sub>2</sub> O <sub>5</sub>	0.06	0.35	0.26	0.16	0.20	0.33	0.14	0.09	0.10	0.49	0.30	0.06
LOI	0.90	0.90	0.80	1.5	3.40	4.2	1.80	0.70	0.90	2.80	0.10	0.30
Cr	5	53	9	26	27	298	3	20	10	182	67	38
Ni	3	56	3	7	7	117	3	7	7	80	59	8
Co	36.2	52.3	35.1	5.9	22.0	48.5	15.2	30.9	20.4	41.1	74.6	105.3
Sc	10.4	31.3	11.3	12.7	16.1	40.5	19.8	7.9	13.3	39.4	15.5	0.9
V	12	333	6	57	97	300	3	31	33	344	71	21
Cu	3	35	3		7		3	3	7	35	105	3
Pb	24	5	19	26	21	11	5	5	27	12	39	5
Zn	18	109	36	60	82	104	175	16	61	137	69	7
Rb	208	9	256	194	61	3	60	48	129	5	31	3
Ba	693	364	410	688	403	141	1275	497	599	116	729	14
Sr	32	302	26	45	131	392	168	74	50	423	457	7
Ga	17.0	23.0	19.0	19.8	20.0	20.8	32.0	14.0	17.0	24.0	14.0	3.0
Ta	1.53	1.57	2.07	1.47	1.80	1.60	6.26	1.28	1.16	2.60	1.04	1.32
Nb	13.0	24.0	14.0	16.1	18.0	19.6	79.0	11.0	12.0	30.0	12.0	3.0
Hf	5.29	4.21	4.90	9.35	9.69	4.06	21.98	4.76	7.15	6.52	3.24	0.16
Zr	169	194	136	289	324	166	946	168	222	277	139	15
Y	28.0	32.0	57.0	46.9	51.0	32.7	122.0	44.0	61.0	52.0	50.0	5.0
Th	17.40	1.87	14.69	19.52	18.41	2.13	10.23	15.82	16.14	2.59	10.54	0.51
U	4.43	0.89	5.18	4.02	4.41	0.34	4.75	3.93	3.84	0.55	2.00	0.27
La	34.51	20.07	25.84	19.34	46.83	21.91	136.37	31.04	158.84	27.22	35.45	2.35
Ce	96.15	43.16	65.51	67.57	103.91	43.37	197.25	68.86	116.95	66.10	124.99	4.02
Nd	44.16	29.16	35.61	21.80	57.69	26.84	136.74	32.33	155.83	37.45	41.05	1.88
Sm	8.46	6.11	7.98	5.61	9.46	6.53	26.54	6.67	24.94	8.81	9.06	0.50
Eu	0.80	2.16	0.43	0.88	1.45	2.09	6.97	0.77	3.57	2.87	2.30	0.11
Tb	0.98	1.25	1.67	1.42	1.37	1.21	5.33	1.03	2.51	2.02	1.52	0.13
Yb	3.24	1.77	5.32	4.71	4.69	2.96	9.00	3.64	5.21	3.91	4.78	0.18
Lu	0.48	0.33	0.71	0.68	0.64	0.46	1.37	0.50	0.73	0.61	0.66	0.03

(Appendix 1 continued)

FIELD #	O/1F-057	O/1F-058	O/1F-059	O/1F-060	O/1F-061	O/1F-064	O/1F-065	O/1F-066	O/1F-067	O/1F-069	O/1F-070	O/1F-072
FORMATION	SR	SK	SK	SK	SK	SK	SK	SR	SK	SK	SR	SK
ROCK TYPE	Sh	Ex	Sh	Ex	Sh	Ex	ML	Sh	Ex	FL	FL	Ex
SiO <sub>2</sub>	59.35	77.54	88.52	68.88	92.24	71.38	45.74	69.93	65.88	72.07	73.24	55.33
TiO <sub>2</sub>	0.85	0.17	0.35	0.52	0.21	0.32	3.93	0.53	0.38	0.19	0.24	0.38
Al <sub>2</sub> O <sub>3</sub>	18.29	3.95	4.91	9.35	3.87	7.64	13.33	12.45	11.49	13.69	14.19	10.14
Fe <sub>2</sub> O <sub>3</sub>	9.09	11.28	0.33	7.93	0.26	11.28	15.13	5.58	11.63	2.82	2.23	24.97
MnO	0.23	0.21	0.01	3.09	0.01	3.24	0.20	0.05	1.88	0.04	0.03	0.15
MgO	2.23	1.20	0.48	1.73	0.26	1.76	5.66	1.85	2.59	1.10	0.93	3.48
CaO	0.08	2.78	0.00	1.79	0.00	2.24	8.41	0.03	1.26	0.07	0.09	1.34
Na <sub>2</sub> O	0.12	0.10	0.19	0.98	0.12	1.11	2.55	1.31	3.48	3.82	3.99	3.85
K <sub>2</sub> O	6.29	0.03	1.25	2.62	0.90	0.26	0.75	3.19	0.58	4.08	3.89	0.52
P <sub>2</sub> O <sub>5</sub>	0.13	0.23	0.03	0.42	0.01	0.26	0.80	0.11	0.19	0.02	0.03	0.40
LOI	3.90	0.90	4.40	1.30	2.30	1.20	3.20	5.40	1.60	1.5	1.20	1.50
Cr	102	32	75	18	50	31	3	99	19	14	5	27
Ni	32	34	3	78	3	65	21	33	70	3	3	33
Co	11.5	77.4	48.2	68.5	44.3	75.1	43.7	25.3	64.7	0.1	25.5	30.7
Sc	18.9	5.9	8.9	14.0	5.0	10.2	32.6	12.6	10.0	2.0	4.6	11.5
V	142	80	412	22	818	42	413	204	33	3	10	95
Cu	25	5	3	3	3	37	28	8	10		3	70
Pb	5	5	11	40	5	30	5	5	39	61	5	5
Zn	81	16	10	69	5	74	135	57	104	130	39	85
Rb	234	3	48	77	32	8	21	114	19	105	135	6
Ba	541	78	259	845	562	126	489	967	226	1239	367	144
Sr	12	274	15	100	9	232	468	55	175	45	58	159
Ga	23.0	7.0	8.0	14.0	8.0	14.0	22.0	23.0	17.0	29.3	23.0	18.0
Ta	1.28	0.81	0.87	0.70	0.83	0.90	3.02	1.19	1.38	5.50	2.82	1.83
Nb	15.0	3.0	6.0	7.0	3.0	6.0	37.0	22.0	18.0	78.2	34.0	20.0
Hf	3.77	1.08	1.24	2.17	0.86	2.32	5.72	3.10	5.39	16.76	8.74	4.99
Zr	142	47	59	94	45	93	241	118	195	498	334	186
Y	24.0	22.0	12.0	46.0	21.0	72.0	43.0	50.0	90.0	61.8	60.0	40.0
Th	12.19	2.59	2.71	5.74	2.55	8.11	2.67	8.15	17.62	21.81	21.83	11.00
U	2.13	0.79	8.31	0.78	5.67	1.82	0.94	6.59	1.16	5.85	6.21	1.19
La	21.70	25.83	9.70	49.91	11.04	51.58	31.34	44.79	122.20	98.48	44.93	94.12
Ce	39.88	67.10	21.91	103.21	21.26	106.71	73.51	96.76	117.86	192.91	196.79	194.39
Nd	15.83	21.98	9.89	45.00	10.02	49.90	47.01	52.89	109.69	104.21	42.62	67.53
Sm	3.80	4.85	2.39	7.78	2.63	10.03	9.28	9.40	21.27	18.26	7.46	11.86
Eu	0.80	1.04	0.44	1.82	0.51	2.12	3.14	1.36	3.98	2.31	0.77	2.11
Tb	0.69	0.62	0.34	1.15	0.45	1.72	1.68	1.42	2.98	2.30	1.38	1.60
Yb	2.72	1.73	1.12	3.99	1.55	4.49	2.98	3.57	5.02	9.92	4.93	3.84
Lu	0.38	0.23	0.19	0.61	0.23	0.59	0.44	0.44	0.67	1.32	0.70	0.56

(Appendix 1 continued)

FIELD # FORMATION ROCK TYPE	O/1F-073 SK Ex	O/1F-074 FL FL	O/1F-075 FL FL	O/1F-076 FL FL	O/1F-077 NF FT	O/1F-078 FL FL	O/1F-079 NF FT	O/1F-080 NF FT	O/1F-081 SK FL	O/1F-082 SK ML	O/1F-083 SK Sh	O/1F-084 SK ML
SiO <sub>2</sub>	77.91	68.79	74.67	75.57	74.67	73.73	74.23	72.51	69.17	48.48	88.96	51.29
TiO <sub>2</sub>	0.27	0.44	0.30	0.23	0.34	0.36	0.33	0.32	0.53	1.16	0.28	1.40
Al <sub>2</sub> O <sub>3</sub>	6.26	15.08	11.56	12.38	12.78	12.24	13.22	12.54	11.64	17.61	5.31	16.56
Fe <sub>2</sub> O <sub>3</sub>	9.76	3.36	2.73	2.45	2.72	2.23	2.64	2.82	8.51	9.26	0.42	10.38
MnO	1.54	0.14	0.06	0.06	0.07	0.14	0.04	0.04	0.10	0.14	0.01	0.16
MgO	1.24	1.62	0.81	0.57	1.11	0.74	1.02	0.96	0.39	5.40	0.41	4.93
CaO	0.58	0.19	0.14	0.03	0.22	1.52	0.31	0.13	0.14	6.17	0.00	7.85
Na <sub>2</sub> O	0.25	3.77	2.15	2.31	3.27	2.53	2.93	1.92	0.84	4.53	0.16	5.45
K <sub>2</sub> O	1.53	3.67	4.90	5.54	3.01	3.99	4.00	5.68	8.18	1.74	1.70	0.40
P <sub>2</sub> O <sub>5</sub>	0.19	0.11	0.09	0.03	0.10	0.10	0.11	0.10	0.03	0.17	0.01	0.18
LOI	1.20	1.2	0.5	1.4	0.9	2.3	1.0	1.0	0.7	3.8	2.9	1.0
Cr	30	19	19	16	24	14	28	15	21	23	68	24
Ni	55	6	7	3	8	3	7	8	3	15	3	27
Co	108.3	1.5	3.6	0.8	3.4	3.2	3.1	3.0	2.9	31.3	0.4	35.1
Sc	8.7	11.9	7.0	11.0	7.2	8.9	7.2	7.1	7.1	26.7	8.0	30.3
V	59	35	25	13	31	28	27	25	3	279	195	297
Cu	28											
Pb	5	5	15	21	11	42	17	18	14	5	14	17
Zn	64	341	91	47	34	63	22	28	239	86	3	79
Rb	51	139	146	118	117	96	93	143	91	30	57	5
Ba	1499	613	780	893	522	635	670	826	707	426	308	76
Sr	49	57	66	42	34	58	55	57	37	276	12	316
Ga	7.0	19.3	15.7	19.0	16.0	16.7	14.3	13.0	35.2	19.6	9.5	16.2
Ta	1.10	1.26	0.99	1.35	1.00	0.99	0.91	1.00	1.00	0.55	0.27	0.40
Nb	12.0	12.0	9.2	14.0	9.4	10.1	8.4	9.4	180.9	9.5	5.4	5.2
Hf	1.96	6.43	4.82	7.99	5.20	4.91	4.92	5.05	5.04	3.05	1.45	2.13
Zr	90	192	137	269	154	158	151	149	1095	122	47	100
Y	25.0	40.4	39.6	49.0	38.2	42.9	41.5	33.7	134.0	26.4	20.7	20.8
Th	5.38	20.32	15.53	16.84	16.85	14.94	16.18	16.31	11.60	3.22	1.63	1.52
U	0.39	4.07	3.77	4.46	3.65	4.13	3.31	3.19	4.22	1.03	3.60	0.48
La	23.19	26.03	49.77	46.28	53.16	37.38	45.34	19.29	106.05	21.08	10.36	13.46
Ce	63.32	68.87	97.50	84.27	89.80	73.42	85.31	68.79	203.91	37.01	23.11	25.57
Nd	21.15	21.26	55.62	39.59	39.93	29.01	42.20	20.27	125.33	21.09	13.52	15.99
Sm	5.70	4.89	10.24	9.06	9.14	7.36	8.68	4.58	24.44	5.23	2.66	3.73
Eu	1.29	0.76	1.27	1.00	1.10	1.10	1.09	0.55	0.55	1.33	0.47	1.19
Tb	0.97	1.15	1.25	1.59	1.32	1.31	1.39	0.87	4.05	0.65	0.39	0.53
Yb	2.37	3.79	3.78	4.97	3.52	3.59	3.64	3.19	14.31	2.65	1.39	1.82
Lu	0.34	0.54	0.52	0.71	0.48	0.53	0.52	0.47	1.95	0.39	0.21	0.27

(Appendix 1 continued)

FIELD # FORMATION ROCK TYPE	O/1F-085 SK FL (alt)	O/1F-086 SK FL (alt)	O/1F-087 CLW FI (f)	O/1F-088 CLW FI (f)	O/1F-089 CLW FI (f)	O/1F-090 SK Ex(?)	O/1F-091 SK Sh	O/1F-092 SK ML	O/1F-093 CW FT	O/1F-094 CW FT	O/1F-095a CW FT	O/1F-095b CW FT
SiO <sub>2</sub>	69.56	77.62	72.66	74.82	74.55	59.39	84.98	39.55	62.74	65.48	65.09	70.30
TiO <sub>2</sub>	0.16	0.15	0.29	0.37	0.21	1.03	0.40	2.01	0.68	0.85	0.82	0.64
Al <sub>2</sub> O <sub>3</sub>	15.13	12.66	14.19	12.06	12.38	19.08	7.20	14.96	16.24	15.19	15.42	14.48
Fe <sub>2</sub> O <sub>3</sub>	3.01	0.64	2.31	3.31	2.26	6.84	0.33	8.72	6.09	5.43	4.92	3.00
MnO	0.02	0.01	0.03	0.06	0.03	0.16	0.01	0.17	0.09	0.06	0.09	0.06
MgO	3.63	0.15	1.90	1.41	0.48	2.61	0.26	5.54	4.02	3.42	3.06	1.41
CaO	0.05	0.00	0.23	0.60	0.12	0.25	0.04	15.72	0.51	0.35	2.45	0.90
Na <sub>2</sub> O	0.17	0.18	2.37	2.93	1.92	1.39	0.69	2.41	1.17	2.04	1.72	2.92
K <sub>2</sub> O	4.77	4.90	2.86	3.14	5.68	4.72	1.97	0.05	3.79	3.53	3.29	4.27
P <sub>2</sub> O <sub>5</sub>	0.06	0.05	0.14	0.12	0.10	0.11	0.02	0.40	0.15	0.21	0.20	0.22
LOI	3.0	1.8	2.1	1.3	2.8	3.9	4.1	9.5	3.6	3.0	3.0	1.6
Cr	15	11	12	18	15	119	57	373	34	25	31	23
Ni	7	3	3	6	3	55	6	165	13	6	12	9
Co	1.9	0.2	1.5	3.2	1.9	29.9	1.2	42.2	7.4	8.7	9.0	4.8
Sc	12.5	10.7	12.3	9.0	10.6	19.4	7.6	27.4	13.9	16.7	16.2	13.5
V	3	7	17	27	9	211	124	214	69	105	90	65
Cu												
Pb	12	25	20	10	24	24	22	13	28	25	39	22
Zn	68	6	57	42	26	109	3	82	67	66	75	58
Rb	209	130	118	97	129	147	73	3	103	87	87	130
Ba	966	659	420	758	798	768	496	31	987	988	735	674
Sr	18	28	62	148	113	47	25	913	39	44	146	58
Ga	19.7	14.0	21.1	15.7	15.3	25.0	10.8	17.1	20.2	19.0	20.4	19.7
Ta	1.84	1.45	1.53	1.20	1.31	1.38	0.02	1.90	1.40	1.36	1.36	1.41
Nb	17.7	13.0	18.0	13.2	14.0	18.0	4.5	31.5	18.6	19.4	17.9	18.6
Hf	4.88	4.76	6.22	8.21	5.42	5.18	1.79	4.23	10.33	8.91	8.64	8.90
Zr	145	147	195	301	163	182	63	214	348	312	320	306
Y	47.0	47.0	63.7	51.3	46.7	40.0	21.5	27.8	36.1	43.0	69.1	54.3
Th	15.37	19.11	22.12	20.82	18.97	17.24	3.25	2.26	22.22	19.90	18.75	20.26
U	11.48	3.33	5.72	6.11	3.28	6.87	2.68	0.43	4.90	3.07	4.28	1.97
La	27.96	47.49	30.25	48.07	27.08	53.69	19.64	21.53	15.38	22.19	104.92	81.64
Ce	57.05	101.95	89.04	113.81	81.58	117.71	54.62	48.76	74.19	113.41	126.60	124.91
Nd	29.46	36.70	30.37	37.14	24.27	49.92	13.88	22.39	14.95	18.13	85.26	85.10
Sm	7.43	9.69	8.27	9.63	6.56	9.34	3.61	5.57	4.07	5.40	17.31	10.66
Eu	0.66	0.96	0.53	1.10	0.85	1.84	0.64	1.82	0.59	0.84	2.67	2.08
Tb	1.44	1.50	1.78	1.65	1.38	1.17	0.54	1.01	0.87	1.05	2.56	2.04
Yb	3.99	4.31	6.60	4.60	4.61	3.84	1.78	2.56	4.19	5.08	7.10	4.11
Lu	0.67	0.61	0.89	0.65	0.61	0.55	0.24	0.30	0.53	0.73	0.97	0.65

(Appendix 1 continued)

FIELD # FORMATION ROCK TYPE	O/1F-096 CW FT	O/1F-097 SR FL	O/1F-098 SR FL	O/1F-099 SR FL	O/1F-100 SK ML	O/1F-101 SR FL	O/1F-102 CW FT	O/1F-103 CLW FI (f)	O/1F-104 SR FL	O/1F-104a CLW FI (f)	O/1F-105 SK ML	O/1F-105a CLW FI (f)
SiO <sub>2</sub>	72.46	65.38	64.70	65.33	45.79	76.07	63.90	68.71	71.30	72.36	44.39	69.68
TiO <sub>2</sub>	0.38	0.76	0.83	0.79	2.01	0.19	0.79	0.53	0.35	0.23	3.30	0.24
Al <sub>2</sub> O <sub>3</sub>	10.56	13.79	14.81	14.97	18.38	12.15	14.43	14.39	13.70	14.58	16.15	15.53
Fe <sub>2</sub> O <sub>3</sub>	3.49	5.03	7.13	4.96	12.09	2.71	9.29	5.28	3.58	2.01	14.09	2.29
MnO	0.03	0.04	0.21	0.15	0.18	0.04	0.11	0.11	0.07	0.02	0.20	0.06
MgO	3.28	2.06	3.11	2.73	5.45	2.22	3.21	2.21	1.69	0.99	6.76	2.40
CaO	2.72	0.20	0.26	0.27	8.32	0.59	0.22	1.16	1.38	0.23	7.24	0.23
Na <sub>2</sub> O	0.44	2.47	2.29	4.25	3.48	1.16	1.63	2.89	3.00	2.42	2.06	1.51
K <sub>2</sub> O	2.06	5.31	3.63	3.21	0.94	2.56	3.15	2.76	2.46	4.03	0.80	4.36
P <sub>2</sub> O <sub>5</sub>	1.52	0.19	0.20	0.19	0.19	0.26	0.19	0.14	0.20	0.15	0.44	0.15
LOI	2.4	3.0	2.9	1.8	1.5	2.4	3.3	2.3	2.0	1.9	4.7	2.5
Cr	30	40	32	31	60	15	29	10	19	8	149	7
Ni	15	3	9	7	29	3	7	3	8	3	71	6
Co	10.7	8.1	8.5	4.2	35.2	1.4	8.3	3.5	3.8	0.8	44.2	1.4
Sc	8.9	15.3	16.3	14.8	34.9		15.3	27.7	13.5	13.0	35.4	13.0
V	36	67	68	65	374	3	92	32	28	11	419	11
Cu												
Pb	21	45	5	5	15	27	5	32	69	0	12	0
Zn	52	58	63	54	104	69	132	97	56	61	118	75
Rb	93	120	89	99	16	108	83	92	76	229	12	209
Ba	484	926	615	657	242	505	684	525	617	486	184	1423
Sr	58	36	28	46	354	64	28	128	208	58	788	35
Ga	13.2	20.2	20.5	18.5	19.9	21.3	19.9	21.2	20.4	0.0	21.5	0.0
Ta	0.83	1.30	1.42	1.34	0.29	0.90	1.23	1.51	1.30	1.80	2.11	1.40
Nb	12.1	16.9	16.5	17.2	5.6	15.3	16.6	22.7	17.0	20.0	33.2	20.0
Hf	4.76	8.39	8.70	8.44	2.06	4.30	8.28	7.94	5.99	5.90	5.19	6.00
Zr	148	284	296	306	97	127	280	314	210	188	248	192
Y	66.5	42.7	42.9	38.3	20.0	51.5	46.3	78.7	63.8	54.0	32.2	58.0
Th	14.51	17.04	19.11	17.88	1.21	13.70	18.00	16.57	21.45	19.40	2.38	20.10
U	2.16	2.99	2.75	3.39	0.96	4.40	3.28	2.40	7.08	4.70	2.32	3.70
La	43.73	43.08	17.74	36.04	9.69	13.00	46.77	119.24	39.66	21.10	24.18	34.10
Ce	83.23	98.04	45.84	65.31	21.57	67.00	101.51	131.24	89.93	69.00	60.41	87.00
Nd	34.23	40.94	17.66	36.35	16.15	17.00	42.62	88.23	38.39	19.00	32.26	31.00
Sm	9.31	8.85	5.01	7.01	3.76	4.18	9.67	9.74	8.95	5.04	7.28	7.70
Eu	0.93	1.60	0.86	1.14	1.26	0.35	2.25	4.14	1.01	0.34	2.41	0.51
Tb	1.68	1.49	1.21	1.06	0.60	1.20	1.62	2.78	1.81	1.30	0.88	1.60
Yb	5.80	4.51	4.32	4.10	1.72	4.99	4.46	7.19	5.80	6.58	2.57	7.17
Lu	0.82	0.60	0.59	0.57	0.25	0.65	0.63	0.99	1.01	0.75	0.39	0.88

(Appendix 1 continued)

FIELD # FORMATION ROCK TYPE	O/1F-108 SR FL (alt)	O/1F-109 SK FL	O/1G-08 NF FT	O/1G-10 NF FT	O/1G-17 NFLF Sh/SI	O/1G-21 NF FT	O/1G-32 FL FL	O/1G-32a PB Sh/SI	O/1G-32b PB Sh/SI	O/1G-34 STB FI (f)	O/1G-36 NFLF Sh/SI	O/1G-37 NFLF Ex
SiO <sub>2</sub>	54.78	61.38	65.71	69.25	59.70	73.96	70.97	62.87	62.72	73.27	70.03	31.97
TiO <sub>2</sub>	0.35	0.56	0.72	0.56	1.05	0.22	0.40	0.99	0.98	0.22	0.67	0.31
Al <sub>2</sub> O <sub>3</sub>	23.07	18.69	16.11	14.74	18.53	13.71	14.68	17.52	18.08	13.38	13.86	5.60
Fe <sub>2</sub> O <sub>3</sub>	3.61	4.51	6.39	5.31	7.94	2.95	3.33	8.74	7.39	2.11	6.56	51.22
MnO	0.10	0.04	0.11	0.20	0.05	0.07	0.07	0.18	0.15	0.03	0.20	2.01
MgO	3.20	2.85	3.11	1.71	2.46	0.99	0.89	1.72	1.46	0.79	1.64	1.25
CaO	0.47	0.85	0.18	0.30	0.00	0.17	0.47	0.14	0.10	0.26	0.48	3.91
Na <sub>2</sub> O	0.97	5.24	0.56	1.73	0.06	1.50	2.37	1.24	2.15	1.22	2.75	0.00
K <sub>2</sub> O	8.09	3.24	3.75	3.38	4.64	3.93	5.13	3.55	3.25	6.47	1.90	0.03
P <sub>2</sub> O <sub>5</sub>	0.12	0.06	0.17	0.18	0.12	0.15	0.12	0.14	0.10	0.24	0.16	1.53
LOI	4.00	1.5	3.90	2.50	4.70	1.60	0.90	2.90	2.60	1.20	1.90	0.30
Cr	0	3	202	78	115	22	25	109	111	19	58	59
Ni	8	4	121	27	23	5	6	36	29	7	20	44
Co	3.9	2.4	8.8	9.5	5.4	2.6	4.1	14.5	12.6	1.1	10.4	13.2
Sc	19.7	20.7	13.7	9.9	19.1	4.3	10.1	16.5	16.8	16.4	15.5	6.6
V	9	7	140	71	216	16	31	180	179	8	98	159
Cu			3	3	49	8	19	26	29	6	8	51
Pb	13	35	60	5	15	5	21	5	18	20	28	2540
Zn	120	156	142	117	81	43	52	95	75	43	84	146
Rb	330	108	142	122	217	152	181	166	158	162	69	8
Ba	1125	1171	491	621	550	515	693	545	524	529	327	3
Sr	121	125	23	49	17	23	78	58	69	39	131	66
Ga			20.0	17.0	25.0	19.0	17.0	22.0	22.0	22.0	15.0	16.0
Ta	1.60	6.50	1.21	0.96	1.55	0.71	1.12	1.45	1.58	1.70	0.90	0.35
Nb	31.0	83.0	13.0	10.0	19.0	8.0	11.0	19.0	18.0	19.0	12.0	3.0
Hf	9.10	22.10	4.50	5.10	5.04	4.27	5.94	8.00	6.35	6.20	5.49	1.62
Zr	282	957	159	162	167	122	186	258	213	172	186	65
Y	55.0	62.0	37.0	41.0	36.0	32.0	41.0	36.0	32.0	74.0	27.0	36.0
Th	31.10	24.40	13.56	14.31	16.43	12.86	17.56	15.85	15.03	19.81	11.24	3.91
U	1.40	1.50	4.80	3.48	8.78	4.77	3.61	3.78	4.00	5.47	2.74	1.05
La	42.40	71.20	45.11	37.97	48.82	19.57	33.40	46.90	44.07	36.53	33.63	19.75
Ce	85.00	172.00	63.70	78.48	100.31	50.56	75.22	103.68	97.17	87.54	61.08	32.48
Nd	39.00	80.00	40.53	37.10	47.36	20.49	29.31	43.01	40.94	40.29	32.46	13.31
Sm	7.82	14.00	8.15	7.70	9.13	5.34	6.99	8.57	7.34	9.81	5.86	3.47
Eu	0.76	4.09	1.57	1.21	1.84	0.57	1.09	1.66	1.53	0.82	1.37	2.21
Tb	1.80	2.60	1.12	1.19	1.22	0.87	1.22	1.18	0.98	1.85	0.79	0.75
Yb	6.96	6.51	3.05	3.60	3.51	2.86	3.84	4.00	3.50	7.42	2.52	1.99
Lu	0.99	0.88	0.47	0.54	0.52	0.45	0.53	0.57	0.51	0.97	0.40	0.32

(Appendix 1 continued)

FIELD # FORMATION ROCK TYPE	O/IG-38 NFLF SH/SI	O/IG-39 NF FT	O/IG-47 NFLF SH/SI	O/IG-48 SK ML	O/IG-50 SK ML	O/IG-51 SK ML	O/IG-55 NF FT	O/IG-56 FL FL	O/IG-60 SK ML	O/IG-62 SR FL	O/IG-68 SK FL	O/IG-69 SK FL
SiO <sub>2</sub>	66.40	75.22	52.17	46.12	46.45	48.33	71.84	74.09	57.80	70.93	71.28	73.25
TiO <sub>2</sub>	0.92	0.32	0.90	2.89	0.96	2.88	0.38	0.31	1.11	0.29	0.35	0.25
Al <sub>2</sub> O <sub>3</sub>	15.15	13.42	21.02	15.71	16.33	15.44	13.74	13.12	14.56	13.75	11.97	12.18
Fe <sub>2</sub> O <sub>3</sub>	7.67	2.33	12.05	9.41	8.56	13.42	3.12	3.52	9.05	3.26	6.57	3.67
MnO	0.26	0.03	1.70	0.29	0.21	0.34	0.03	0.06	0.12	0.05	0.09	0.04
MgO	2.06	1.25	2.19	3.56	5.16	7.86	0.76	1.23	5.54	1.29	0.13	0.12
CaO	0.36	0.29	0.64	8.30	9.00	4.01	0.16	0.14	3.03	0.04	0.11	0.03
Na <sub>2</sub> O	0.92	1.46	2.41	3.93	4.41	2.37	1.80	4.41	3.05	0.68	3.50	3.44
K <sub>2</sub> O	2.95	3.41	2.76	1.73	0.82	0.17	5.74	1.44	1.37	8.08	4.91	5.57
P <sub>2</sub> O <sub>5</sub>	0.33	0.11	0.30	0.48	0.15	0.38	0.12	0.07	0.15	0.09	0.02	0.04
LOI	2.70	1.90	3.00	8.20	9.00	4.90	1.10	1.00	5.10	0.60	0.10	0.3
Cr	156	29	138	256	181	244	28	24	211	18	28	14
Ni	24	6	59	94	20	78	9	3	60	5	3	3
Co	8.4	0.5	8.2	42.3	29.4	44.4	2.7	3.9	23.5	6.5	0.5	0.4
Sc	15.7	6.9	19.7	31.5	34.1	36.1	9.6	10.8	19.5	20.8	1.0	0.4
V	134	26	172	320	286	374	26	17	128	9	3	3
Cu	13	5	18	42	5	46	9	11	48	9	10	
Pb	11	22	34	13	5	15	26	18	5	11	17	
Zn	107	33	94	113	80	128	55	49	142	80	191	107
Rb	98	107	131	54	33	3	142	57	41	188	81	117
Ba	502	635	508	273	118	83	913	233	433	820	116	135
Sr	36	52	96	134	185	276	58	49	66	39	8	13
Ga	17.0	17.0	25.0	22.0	17.0	22.0	15.0	15.0	24.0	17.0	41.0	35.7
Ta	1.31	1.02	1.18	2.06	0.48	1.71	1.04	1.02	3.08	1.70	7.80	9.77
Nb	14.0	10.0	16.0	30.0	6.0	24.0	10.0	12.0	49.0	20.0	120.0	136.0
Hf	6.52	4.83	3.51	5.81	1.90	5.25	6.15	6.90	12.88	9.16	27.72	25.71
Zr	214	150	120	238	77	215	176	247	530	297	1139	1127
Y	26.0	23.0	31.0	33.0	17.0	39.0	34.0	35.0	72.0	71.0	155.0	122.3
Th	12.77	15.45	13.04	3.80	3.76	2.80	17.44	14.99	8.92	21.56	17.92	23.54
U	2.72	3.19	2.38	0.95	0.92	1.10	3.52	3.65	1.93	5.35	4.56	3.87
La	45.47	21.12	42.72	24.16	13.19	25.41	11.84	30.55	48.25	66.51	162.28	110.67
Ce	96.55	37.84	108.34	52.18	26.83	50.90	59.03	71.66	109.26	144.30	263.83	242.40
Nd	38.37	12.35	39.13	26.21	13.20	31.12	12.02	29.62	51.79	67.44	172.61	102.78
Sm	7.93	2.95	7.73	5.84	3.12	6.67	3.75	5.84	11.91	13.73	29.71	21.77
Eu	1.63	0.40	1.70	1.83	1.09	2.43	0.56	0.97	2.99	1.54	5.27	3.51
Tb	1.00	0.67	1.16	0.82	0.47	0.97	0.86	0.96	1.72	2.19	3.58	4.20
Yb	2.66	2.47	3.15	2.97	1.95	2.84	3.67	3.63	6.36	6.84	12.83	12.61
Lu	0.42	0.38	0.44	0.41	0.25	0.39	0.49	0.55	0.87	0.95	1.72	2.33

(Appendix 1 continued)

FIELD # FORMATION ROCK TYPE	O/IG-71 SK ML	O/IG-72 CLW FI (f)	O/IG-73 SR Sh	O/IG-74 SQF FI (f)	O/IG-75 SK FL	O/IG-76 SK ML	O/IG-77 SR FL	O/IG-78 SR FL	O/IG-79 SR FL	O/IG-80 CLW FI (f)	O/IG-81 Omi MI	O/IG-82 PB Sh/SI
SiO <sub>2</sub>	59.23	69.10	82.17	68.45	77.59	43.67	74.51	72.61	68.19	69.59	44.47	60.71
TiO <sub>2</sub>	0.71	0.40	0.41	0.76	0.14	3.77	0.14	0.17	0.38	0.42	2.48	0.99
Al <sub>2</sub> O <sub>3</sub>	16.57	15.50	9.26	14.67	11.09	14.54	12.73	13.04	14.32	14.79	15.00	19.40
Fe <sub>2</sub> O <sub>3</sub>	10.09	3.52	0.78	5.48	1.14	13.09	2.18	3.67	4.41	3.27	12.10	7.43
MnO	0.14	0.05	0.01	0.08	0.02	0.21	0.04	0.02	0.04	0.07	0.18	0.05
MgO	3.25	1.38	0.96	1.32	0.06	9.25	1.42	3.42	4.38	1.00	7.80	1.99
CaO	2.32	0.50	0.00	0.35	0.03	5.18	0.38	0.06	0.03	0.14	8.15	0.09
Na <sub>2</sub> O	3.61	1.79	0.09	4.17	2.48	1.67	3.88	1.31	0.19	1.09	2.11	0.39
K <sub>2</sub> O	1.43	5.04	2.36	3.43	5.46	0.57	1.72	2.27	4.21	7.78	0.49	4.73
P <sub>2</sub> O <sub>5</sub>	0.13	0.10	0.03	0.17	0.02	1.26	0.02	0.01	0.05	0.15	0.29	0.10
LOI	2.60	2.30	3.20	1.4	0.4	7.0	1.3	2.6	3.4	1.7	6.4	3.9
Cr	7	24	104	53	15	3	10	16	25	10	272	129
Ni	3	3	9	19	3	7	3	3	9	3	140	25
Co	1.3	2.8	0.5	12.8	12.8	32.8	0.4	0.7	3.9	3.9	46.3	4.8
Sc	27.5	10.5	11.5	14.3	13.7	33.9	0.5	1.1	2.1	11.5	32.9	18.4
V	3	16	247	89	3	400	3	3	21	27	300	186
Cu	10	10	3									
Pb	14	25	34	15	19	16	25	5	15	36	10	5
Zn	215	54	24	77	27	134	116	118	165	56	108	53
Rb	33	223	83	149	117	16	66	76	128	226	12	203
Ba	1222	645	619	449	218	174	83	1313	955	1012	220	688
Sr	352	57	29	48	20	108	65	66	26	45	312	51
Ga	36.0	21.0	14.0	18.1	23.4	22.9	26.0	31.9	34.6	19.3	19.4	26.6
Ta	4.70	1.37	0.52	1.29	1.15	3.81	5.55	5.75	6.60	1.38	1.27	1.52
Nb	85.0	18.0	7.0	14.9	62.9	51.8	69.9	72.1	122.2	16.6	18.2	19.4
Hf	26.82	10.35	2.31	7.26	6.72	8.24	12.59	14.55	12.41	10.06	4.25	4.17
Zr	1203	366	84	262	338	316	348	423	444	348	173	152
Y	127.0	61.0	32.0	55.0	62.7	61.1	62.8	52.9	152.2	69.5	29.9	46.7
Th	11.70	28.17	4.42	19.46	17.12	3.99	22.98	28.01	22.35	32.36	2.10	17.59
U	2.80	6.01	7.68	4.13	5.06	1.40	3.00	2.78	8.10	7.61	0.50	8.87
La	88.83	59.46	37.82	91.00	34.04	57.10	63.47	125.97	32.54	61.92	21.81	59.48
Ce	172.21	129.62	50.54	168.58	89.75	107.96	157.50	240.42	73.81	123.95	42.97	120.98
Nd	106.90	50.76	23.35	83.97	35.86	57.01	59.02	119.35	35.34	55.15	26.89	53.95
Sm	22.75	11.65	7.22	16.83	7.90	13.73	11.11	22.04	8.53	12.19	5.70	10.06
Eu	6.18	1.06	0.78	2.32	0.97	4.17	1.05	2.25	0.84	1.32	2.12	1.90
Tb	2.85	1.79	0.86	2.39	2.28	1.77	2.08	2.80	2.82	2.39	0.66	1.33
Yb	11.12	5.43	2.96	4.68	7.51	4.35	8.11	8.25	16.93	6.52	2.36	2.17
Lu	1.53	0.79	0.44	0.86	1.34	0.78	1.53	1.62	2.61	1.25	0.42	0.55

(Appendix 1 continued)

FIELD # FORMATION ROCK TYPE	O/G-83 SR FL	O/G-84 SR FL	O/G-85 SR FL	O/G-86 SK ML	O/G-87 PB SH/SI	O/G-88 SR FL	O/G-89 SR FL	O/G-90 SK ML	O/G-SH1 SK ML	O/G-SH2 SK FL	O/G-SH3 SR Sh	O/H-888 SQF FI (f)
SiO <sub>2</sub>	70.92	67.08	72.98	45.16	48.98	72.32	68.92	44.60	42.38	70.73	63.60	68.48
TiO <sub>2</sub>	0.42	0.65	0.43	2.83	1.27	0.17	0.35	2.28	3.31	0.21	0.63	0.56
Al <sub>2</sub> O <sub>3</sub>	13.35	15.57	14.26	14.26	24.24	12.85	13.62	13.46	17.91	10.94	15.59	14.98
Fe <sub>2</sub> O <sub>3</sub>	2.95	3.44	2.89	12.24	9.59	3.37	2.98	11.57	15.82	6.40	5.49	3.74
MnO	0.05	0.03	0.04	0.38	0.05	0.03	0.03	0.18	0.25	0.09	0.06	0.06
MgO	0.64	1.26	1.13	6.90	3.11	4.22	1.17	6.60	6.31	4.11	2.98	1.96
CaO	0.11	0.16	0.81	7.22	0.05	0.02	0.12	10.18	2.86	0.00	0.68	0.55
Na <sub>2</sub> O	1.42	0.76	2.96	2.89	0.38	0.86	0.23	3.72	4.05	0.06	1.73	3.06
K <sub>2</sub> O	7.91	8.43	3.85	0.68	5.74	2.82	8.66	0.52	0.49	2.80	2.85	4.53
P <sub>2</sub> O <sub>5</sub>	0.10	0.18	0.14	0.34	0.09	0.02	0.13	0.36	1.49	0.02	0.17	0.14
LOI	1.3	1.6	1.9	7.5	5.0	3.1	1.9	6.4	5.30	4.00	4.60	2.00
Cr	14	20	22	204	139	15	21	374	3	20	127	26
Ni	3	3	3	68	38	3	8	190	5	7	27	8
Co	1.4	6.2	3.4	38.6	8.2	0.5	2.5	44.7	22.9	2.9	9.8	7.1
Sc	10.9	14.7		34.4	25.3		7.3	26.9	26.7	1.3	14.4	12.7
V	24	59	26	324	219	3	32	263	196	3	195	59
Cu									8	57	41	6
Pb	51	31	24	20	17	16	10	13	5	12	5	39
Zn	71	55	56	113	49	163	56	99	258	182	104	93
Rb	169	186	125	14	234	78	15	10	6	58	99	141
Ba	755	685	470	300	785	1123	111	381	298	392	731	599
Sr	62	32	72	213	52	38	71	239	161	10	58	74
Ga	18.1	22.3	19.0	21.4	33.0	28.7	13.5	17.2	32.0	34.0	20.0	14.0
Ta	1.38	1.24	1.10	1.33	1.43	3.50	1.18	1.11	5.06	7.79	0.81	0.97
Nb	14.8	18.7	14.6	24.0	21.5	68.4	17.1	19.4	77.0	129.0	11.0	13.0
Hf	9.51	9.07	7.80	4.75	5.08	13.30	8.03	4.14	12.24	23.59	2.99	6.80
Zr	321	296	314	197	176	388	295	177	496	1045	100	205
Y	50.3	59.2	122.6	33.9	48.5	28.6	58.0	29.4	93.0	131.0	21.0	55.0
Th	28.60	23.07	24.50	2.38	20.38	16.70	27.26	2.29	5.30	19.29	11.05	19.40
U	6.65	5.76	5.00	0.37	5.21	2.60	7.38	1.97	1.38	5.09	4.53	4.98
La	47.98	61.22	159.00	25.41	67.76	4.10	22.11	21.87	54.75	115.46	39.42	55.09
Ce	118.17	131.53	139.00	45.97	137.53	79.00	46.80	47.68	133.50	194.53	76.98	98.89
Nd	45.77	55.30	117.00	31.51	55.39	5.00	24.76	27.64	82.21	107.28	36.98	54.20
Sm	9.67	11.65	22.70	6.38	11.81	1.54	6.37	6.00	16.80	23.33	6.36	10.65
Eu	1.07	1.83	2.31	2.08	1.84	0.40	0.64	1.92	5.10	2.27	1.25	1.52
Tb	1.75	2.09	4.40	0.91	1.81	0.60	1.47	0.81	2.15	3.51	0.77	1.50
Yb	5.46	5.71	7.76	2.73	4.62	5.96	4.93	2.18	6.96	11.52	1.49	4.76
Lu	0.97	1.03	0.96	0.44	0.67	0.88	0.84	0.30	0.85	1.52	0.27	0.65

(Appendix 1 continued)

FIELD #	Q/1H-0028	Q/1H-0032	Q/1H-0037	Q/1H-0054	Q/1H-0082	Q/1H-0097	Q/1H-0118	Q/1H-0124	Q/1H-0185	Q/1H-0180	Q/1H-0292	Q/1H-0338
FORMATION	SQF	SQF	SQF	FLFM	LRBM	NF	LRBM	SQF	STB	STB	KB	SQF
ROCK TYPE	FI (f)	FI (f)	FI (f)	ML	ML	FT	ML	FI (f)	FI (f)	FI (f)	W	FI (f)
SiO <sub>2</sub>	69.81	68.75	68.50	47.14	45.32	72.62	38.55	67.69	74.54	66.84	82.07	69.78
TiO <sub>2</sub>	0.59	0.80	0.58	1.23	3.09	0.29	2.81	0.59	0.23	0.61	0.55	0.65
Al <sub>2</sub> O <sub>3</sub>	14.72	14.36	14.76	15.54	15.69	14.16	16.61	14.42	12.92	15.11	7.57	14.92
Fe <sub>2</sub> O <sub>3</sub>	5.00	5.59	4.99	10.56	12.99	2.09	16.42	5.23	2.51	3.53	4.09	4.62
MnO	0.04	0.06	0.07	0.19	0.15	0.04	0.18	0.05	0.02	0.03	0.03	0.04
MgO	2.03	2.09	1.69	7.78	7.16	0.94	11.68	2.07	0.82	1.28	0.88	1.36
CaO	0.18	0.20	0.24	8.39	4.82	0.94	4.76	0.22	0.35	0.26	0.09	0.15
Na <sub>2</sub> O	4.89	3.55	2.99	3.38	3.72	2.72	1.68	2.13	2.00	1.39	2.82	3.54
K <sub>2</sub> O	1.01	2.37	3.82	0.42	0.31	3.74	0.39	4.86	6.02	8.31	0.29	2.96
P <sub>2</sub> O <sub>5</sub>	0.15	0.17	0.21	0.10	0.34	0.14	0.25	0.19	0.28	0.19	0.12	0.17
LOI	1.70	2.10	1.80	4.80	6.0	2.00	7.3	1.80	1.10	1.30	0.80	1.80
Cr	51	73	28	512	314	19	330	29	18	18	38	50
Ni	9	19	8	190	96	5	107	6	3	7	9	12
Co	5.5	6.4	6.1	46.4	46.6	2.3	54.6	6.5	0.9	4.0	3.4	4.0
Sc	10.1	14.2	18.6	36.9	36.0	5.0	41.2	16.2	17.6	11.1	4.0	11.3
V	65	100	52	281	434	23	454	49	6	40	31	73
Cu	15	15	5	59		3		8	3	15	3	8
Pb	5	5	14	5	5	5	15	13	39	45	5	5
Zn	37	42	55	80	112	45	137	63	54	46	33	44
Rb	42	79	135	8	5	122	7	182	156	227	12	92
Ba	228	447	633	35	112	443	85	679	508	737	43	508
Sr	56	41	39	225	159	46	136	36	46	30	28	45
Ga	14.0	13.0	20.0	11.0	18.2	15.0	23.1	17.0	19.0	20.0	3.0	16.0
Ta	1.11	1.11	1.11	0.22	0.80	1.02	1.35	1.28	1.49	1.34	1.41	1.21
Nb	14.0	15.0	17.0	6.0	22.8	10.0	20.7	16.0	19.0	18.0	21.0	14.0
Hf	7.45	7.27	10.09	2.03	4.17	5.01	3.91	9.23	5.97	9.77	11.67	7.65
Zr	240	229	332	84	191	145	166	306	169	355	394	248
Y	47.0	39.0	71.0	29.0	35.2	47.0	31.7	59.0	90.0	58.0	24.0	47.0
Th	18.11	12.72	22.43	0.66	1.64	15.99	1.31	19.86	17.55	21.54	10.90	17.82
U	3.69	4.73	4.04	0.29	1.21	4.14	0.03	3.70	6.54	5.71	3.18	4.55
La	33.35	19.02	70.58	3.47	13.87	37.65	24.12	32.56	59.38	45.60	31.02	39.20
Ce	73.82	42.50	135.37	9.45	38.49	69.09	37.63	70.53	119.63	96.14	67.73	88.07
Nd	34.85	16.43	63.27	8.62	23.49	35.36	23.56	34.83	62.91	45.19	27.79	45.16
Sm	6.91	4.41	13.03	2.99	4.55	7.93	5.47	7.09	16.45	9.90	5.76	8.01
Eu	1.10	0.73	1.78	1.18	2.01	0.86	2.08	1.02	1.08	1.21	1.13	1.00
Tb	1.18	0.91	1.80	0.67	1.03	1.29	0.72	1.28	2.24	1.59	0.81	1.32
Yb	4.27	3.74	6.71	2.85	2.54	3.60	2.07	5.52	7.55	4.75	2.49	3.98
Lu	0.57	0.56	0.95	0.42	0.35	0.52	0.39	0.80	1.05	0.71	0.39	0.56

(Appendix 1 continued)

FIELD # FORMATION ROCK TYPE	O/1H-0348O/1H-0378b STB FI (f)	O/1H-0389O/1H-0415bO/1H-0421 KB W	O/1H-0430 PB SN/SI	O/1H-0478 STB FI (f)	O/1H-0492 STB FI (f)	O/1H-0525 STB FI (f)	O/1H-0552O/1H-0581aO/1H-0581b STB FI (f)	FLFM ML	NF FT	LRBM ML	FL FL	FL SI
SiO <sub>2</sub>	74.98	91.54	65.62	75.92	68.43	68.03	68.49	47.68	74.86	46.05	77.88	72.84
TiO <sub>2</sub>	0.17	0.44	1.05	0.15	0.34	0.24	0.57	2.81	0.26	2.11	0.13	0.31
Al <sub>2</sub> O <sub>3</sub>	12.33	4.04	16.54	11.57	14.60	15.89	14.03	13.43	12.71	13.58	11.28	6.22
Fe <sub>2</sub> O <sub>3</sub>	2.40	2.09	7.18	1.69	4.09	2.71	4.80	14.35	2.18	10.30	1.13	8.62
MnO	0.03	0.01	0.06	0.03	0.06	0.05	0.11	0.24	0.05	0.14	0.04	1.01
MgO	0.91	0.38	1.72	0.58	1.42	1.70	2.31	7.41	0.95	5.29	0.40	3.99
CaO	0.73	0.09	0.05	0.37	0.37	0.96	0.24	6.99	0.56	9.88	0.18	3.35
Na <sub>2</sub> O	1.74	1.16	1.66	0.91	2.01	0.66	3.23	3.75	0.70	2.10	3.98	0.03
K <sub>2</sub> O	3.89	0.55	3.40	6.75	6.60	6.18	4.05	0.17	5.19	1.36	2.78	0.40
P <sub>2</sub> O <sub>5</sub>	0.30	0.11	0.08	0.27	0.27	0.36	0.17	0.29	0.12	0.43	0.01	0.17
LOI	1.60	0.70	3.2	0.90	1.30	2.70	1.60	3.40	1.70	9.20	0.8	4.2
Cr	19	35	104	18	11	9	25	188	18	229	15	56
Ni	5	3	26	3	3	5	8	51	6	59	3	69
Co	1.1	1.4	4.6	1.2	2.3	0.7	6.7	36.6	2.5	37.1	1.0	87.2
Sc	14.0	1.7	17.9	12.8	21.8	20.0	15.3	46.0	4.3	33.2	2.8	10.4
V	7	14	171	6	7	9	53	502	19	245	3	87
Cu	3	3		5	5	3	3	57	7	55		
Pb	18	5	19	18	20	26	5	5	19	5	10	12
Zn	63	20	70	61	75	86	74	126	45	87	45	59
Rb	130	21	155	137	134	288	107	6	140	16	146	13
Ba	219	160	572	685	1213	430	549	67	528	412	553	120
Sr	45	13	40	50	38	40	65	108	36	212	17	30
Ga	16.0	3.0	22.9	14.0	16.0	26.0	13.0	17.0	13.0	15.0	16.6	5.0
Ta	1.29	0.91	1.44	1.20	1.32	1.79	1.15	0.68	0.92	1.70	1.46	0.20
Nb	13.0	14.0	16.6	14.0	18.0	22.0	15.0	11.0	9.0	25.0	17.1	6.0
Hf	4.34	9.50	5.64	4.05	9.33	6.53	8.79	5.00	4.53	5.75	4.83	1.71
Zr	119	328	183	109	319	189	305	172	125	241	297	57
Y	60.0	18.0	31.2	65.0	110.0	102.0	57.0	64.0	51.0	36.0	61.2	28.0
Th	12.10	6.83	15.39	11.05	33.60	19.76	18.90	0.60	13.94	2.33	23.87	4.62
U	6.84	1.36	3.13	3.93	4.55	7.90	3.24	0.74	4.08	0.92	4.21	0.30
La	23.65	13.34	43.76	37.85	126.38	48.90	51.88	9.00	37.11	21.60	105.54	24.17
Ce	46.09	38.91	100.66	62.61	253.34	99.97	110.27	23.30	63.56	49.21	119.27	50.74
Nd	25.92	10.49	41.91	37.84	115.78	54.80	51.10	18.41	36.13	27.88	74.58	17.57
Sm	7.11	2.01	7.23	7.94	21.82	13.78	10.24	6.49	7.83	6.90	12.85	4.14
Eu	0.35	0.70	1.45	0.41	1.91	0.92	1.48	2.18	0.92	2.87	1.40	0.91
Tb	1.42	0.49	1.14	1.54	3.05	2.43	1.65	1.43	1.43	1.25	1.90	0.60
Yb	5.72	1.04	3.52	4.26	9.91	8.75	5.26	5.47	4.30	2.99	4.47	2.53
Lu	0.80	0.14	0.50	0.60	1.39	1.22	0.76	0.82	0.58	0.44	0.64	0.35

(Appendix 1 continued)

FIELD #	O/1H-0582	O/1H-0582	O/1H-0589	O/1H-0646	O/1H-0666	O/1H-0677	O/1H-0721	O/1H-0873	O/1H-0910	O/1H-0912	O/1H-0920	O/1H-0941
FORMATION	NF	FL	LRBM	PB	STB	STB	SR	NFLF	FL	FL	FL	FLFM
ROCK TYPE	FT	FL	ML	Sh/SI	FI (f)	FI (f)	FL	Sh/SI	FL	FL	FL	ML
SiO <sub>2</sub>	75.46	69.67	44.29	49.47	70.11	70.71	68.70	61.26	78.51	77.26	77.50	46.72
TiO <sub>2</sub>	0.25	0.26	2.55	1.25	0.37	0.45	0.63	1.15	0.19	0.22	0.22	1.93
Al <sub>2</sub> O <sub>3</sub>	11.95	13.44	15.06	24.52	13.51	14.26	14.62	17.21	11.30	12.44	11.26	13.81
Fe <sub>2</sub> O <sub>3</sub>	2.17	3.30	12.91	9.00	3.17	3.15	3.28	8.04	1.69	1.94	2.16	12.81
MnO	0.04	0.07	0.16	0.08	0.04	0.05	0.04	0.11	0.05	0.03	0.03	0.19
MgO	0.49	2.90	6.71	2.93	1.40	0.65	1.31	3.10	0.82	0.85	0.77	7.55
CaO	1.14	1.55	8.21	0.01	0.63	0.56	0.12	1.54	0.35	0.12	0.47	10.95
Na <sub>2</sub> O	4.19	5.04	3.36	0.30	1.50	3.77	0.08	2.39	3.20	1.04	2.38	1.42
K <sub>2</sub> O	2.10	0.81	0.72	6.02	7.06	5.56	8.47	2.72	1.87	3.81	2.53	0.21
P <sub>2</sub> O <sub>5</sub>	0.10	0.03	0.32	0.08	0.07	0.09	0.15	0.20	0.02	0.03	0.02	0.21
LOI	1.70	2.0	5.5	5.4	1.60	0.60	1.90	2.5	1.00	0.3	1.8	4.20
Cr	25	14	60	139	13	21	40	140	16	16	10	471
Ni	3	5	52	26	5	3	8	52	3	3	8	174
Co	3.7	10.0	51.4	5.4	2.4	3.6	5.3	20.0	0.7	1.1	1.4	49.4
Sc	4.8		31.8	28.6	8.7	9.9	10.7	19.1	7.0	8.8	8.4	38.5
V	14	21	317	225	27	25	54	156	5	7	3	346
Cu	17				3	3	76		3			59
Pb	25	29	5	28	22	14	18	26	5	10	11	5
Zn	59	38	110	89	54	42	74	109	48	33	43	103
Rb	67	234	10	264	199	192	178	71	72	68	85	6
Ba	331	669	115	911	781	665	990	673	308	581	479	37
Sr	87	26	233	34	68	38	54	175	41	59	36	186
Ga	7.0	17.0	20.3	35.0	16.0	16.0	16.0	22.8	7.0	11.3	14.9	16.0
Ta	0.87	1.40	1.32	1.31	1.24	1.31	1.23	1.73	1.24	1.47	1.38	0.64
Nb	9.0	14.0	24.6	19.1	13.0	15.0	13.0	20.2	15.0	12.2	16.4	10.0
Hf	4.63	7.90	4.14	5.05	9.41	10.55	7.59	5.56	7.32	8.79	8.25	3.66
Zr	132	285	178	180	297	353	262	196	246	135	277	131
Y	39.0	48.8	25.8	37.0	55.0	56.0	47.0	18.6	58.0	56.5	58.9	42.0
Th	14.31	18.50	1.95	18.99	25.08	24.36	17.72	15.25	15.77	18.75	17.44	0.53
U	4.22	4.20	0.53	9.97	6.64	6.64	4.85	2.35	2.96	4.43	4.72	0.47
La	29.03	56.80	20.86	59.62	53.86	53.18	45.13	18.99	73.84	58.79	47.19	8.68
Ce	64.91	117.00	41.72	122.37	117.48	115.93	98.77	39.40	105.23	116.29	97.16	24.36
Nd	28.73	51.00	21.27	51.15	49.17	51.02	44.52	12.76	66.80	49.12	52.20	14.91
Sm	6.28	9.88	5.45	10.81	10.61	11.10	9.40	3.54	13.27	11.72	9.80	4.90
Eu	0.70	1.05	1.76	2.16	0.99	1.16	1.30	0.69	1.65	1.48	1.34	1.62
Tb	1.11	1.50	0.76	1.47	1.78	1.82	1.52	0.42	1.72	1.94	1.76	0.82
Yb	3.33	5.30	1.95	3.51	5.09	5.11	4.29	1.97	4.96	5.54	5.54	3.61
Lu	0.46	0.76	0.32	0.53	0.71	0.72	0.60	0.41	0.71	0.88	0.79	0.56

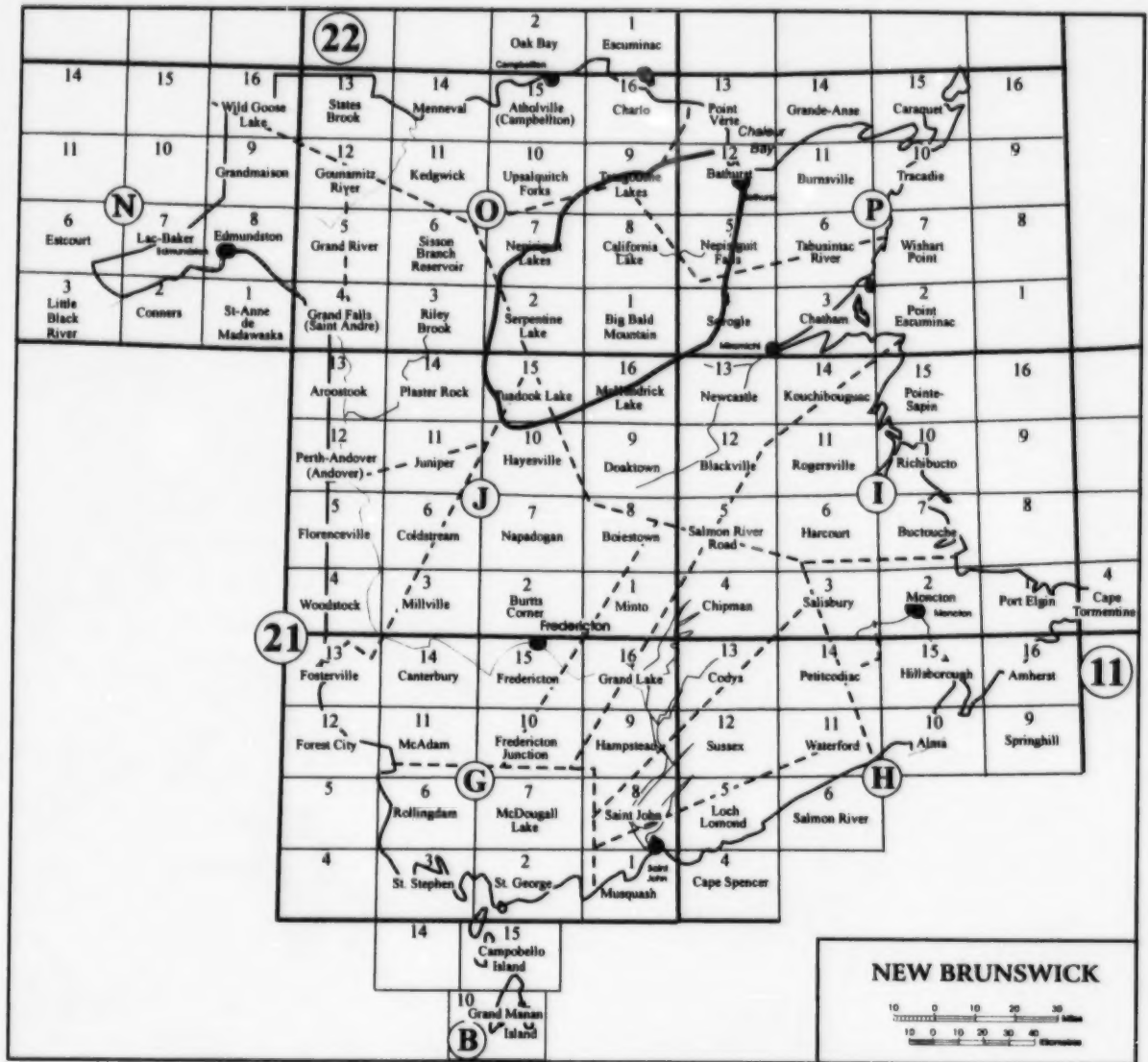
(Appendix 1 continued)

FIELD #	O/H-0955	O/H-0961	O/H-1010	O/H-1128	O/H-1285	O/H-1288	O/H-1289	O/H-1292a	O/H-1292b	O/H-1343	O/H-1355	O/H-1374
FORMATION	FL	LRBM	NF	SQF	NF	CBK	NFLF	NFLF	NFLF	FLFM	FL	FL
ROCK TYPE	FL	ML	FT	FI (f)	FT	FI	Sh/SI	Sh/SI	Sh/SI	ML	FT	FL
SiO <sub>2</sub>	75.69	48.66	76.39	73.37	72.95	72.98	53.36	66.87	77.06	45.12	70.43	77.35
TiO <sub>2</sub>	0.26	2.36	0.24	0.45	0.26	0.34	1.17	1.04	0.84	1.97	0.59	0.22
Al <sub>2</sub> O <sub>3</sub>	12.91	13.93	12.04	14.01	14.02	13.81	21.77	15.33	10.51	14.33	12.39	12.56
Fe <sub>2</sub> O <sub>3</sub>	2.24	11.63	1.60	3.90	2.14	2.73	9.51	5.51	5.98	13.68	4.70	1.60
MnO	0.04	0.15	0.01	0.05	0.02	0.03	0.07	0.04	0.06	0.18	0.07	0.02
MgO	1.47	4.11	0.63	0.75	0.79	0.55	2.79	1.67	1.49	7.28	1.78	0.57
CaO	0.21	8.47	0.14	0.24	0.17	0.96	0.05	0.12	0.10	7.65	2.01	0.00
Na <sub>2</sub> O	1.02	5.77	2.85	7.05	2.50	4.21	1.47	0.22	0.84	2.65	2.00	2.41
K <sub>2</sub> O	3.73	0.54	3.37	0.08	4.81	2.61	4.48	4.09	2.05	0.02	2.38	3.51
P <sub>2</sub> O <sub>5</sub>	0.02	0.28	0.12	0.13	0.13	0.08	0.12	0.12	0.13	0.18	0.17	0.02
LOI	2.2	5.10	1.20	0.90	1.40	1.40	4.6	2.9	2.1	7.30	3.10	1.40
Cr	10	68	17	29	29	28	132	89	58	424	20	9
Ni	3	39	3	3	6	3	20	24	9	170	6	3
Co	1.1	40.1	2.1	2.5	1.7	3.1	8.6	10.3	5.5	50.9	5.3	0.7
Sc	9.6	29.8	3.9	11.5	4.7	11.0	23.7	15.3	10.5	38.1	14.5	8.9
V	9	277	15	48	19	20	187	123	79	351	23	3
Cu		35	5	10	3	3				51	3	3
Pb	11	5	5	10	21	14	16	22	13	5	5	5
Zn	61	96	25	59	41	24	91	84	58	123	102	38
Rb	131	11	106	3	156	56	186	155	80	3	87	104
Ba	736	131	492	34	832	710	656	649	350	3	450	602
Sr	24	88	45	90	38	113	65	36	22	95	80	31
Ga	16.1	9.0	10.0	9.0	15.0	17.0	30.9	22.4	12.6	11.0	20.0	11.0
Ta	1.40	1.72	0.89	0.99	0.94	1.29	1.72	1.30	1.19	0.51	2.84	1.36
Nb	18.4	24.0	9.0	10.0	9.0	15.0	20.5	15.1	12.1	8.0	40.0	18.0
Hf	9.33	4.26	4.32	6.16	4.24	8.98	5.17	6.40	9.42	3.62	12.65	8.64
Zr	310	159	129	205	130	266	180	230	287	112	443	264
Y	64.9	26.0	36.0	34.0	33.0	53.0	48.3	42.6	35.0	51.0	65.0	63.0
Th	19.61	1.77	13.88	14.04	13.85	18.33	19.79	11.71	12.73	0.50	17.21	18.56
U	4.45	0.00	3.76	3.34	4.71	6.98	5.09	2.87	2.59	0.66	2.39	3.61
La	66.05	16.86	29.78	9.56	8.35	75.14	68.94	42.46	37.69	6.03	68.58	50.58
Ce	118.73	37.82	56.58	20.99	36.14	99.64	121.30	88.16	94.75	16.03	136.94	128.72
Nd	58.87	19.84	27.86	7.91	13.12	50.71	53.61	41.78	34.65	11.38	69.25	48.55
Sm	12.05	5.14	5.90	2.70	2.80	13.77	11.00	8.54	7.20	4.70	13.48	10.61
Eu	1.60	1.71	0.68	0.44	0.31	1.23	2.04	1.56	1.45	1.37	2.71	1.50
Tb	2.10	0.62	1.09	0.80	0.82	1.51	1.57	1.45	1.12	0.91	2.01	1.77
Yb	6.14	1.78	3.20	3.05	3.18	5.75	4.34	4.10	3.58	3.92	5.69	5.48
Lu	0.94	0.25	0.44	0.44	0.45	0.78	0.59	0.59	0.54	0.59	0.78	0.82

(Appendix 1 concluded)

FIELD #	O/1H-1393	O/1H-1395	O/1H-1414	O/1H-1475	O/1H-1503	O/1H-1537	O/1H-1572
FORMATION	FL	FL	NF	NF	NF	FL	NFLF
ROCK TYPE	FL	FL	FT	FT	FT	FT	SN/SI
SiO <sub>2</sub>	73.73	68.64	75.24	75.26	67.92	65.44	63.31
TiO <sub>2</sub>	0.33	0.54	0.29	0.32	0.55	0.58	0.92
Al <sub>2</sub> O <sub>3</sub>	14.61	13.20	13.59	13.18	13.00	14.14	16.70
Fe <sub>2</sub> O <sub>3</sub>	2.26	4.88	1.55	2.27	5.40	6.34	6.94
MnO	0.04	0.11	0.02	0.12	0.07	0.06	0.07
MgO	0.65	1.13	0.73	0.90	3.06	4.57	2.31
CaO	0.24	2.14	0.12	0.21	1.73	1.20	0.43
Na <sub>2</sub> O	6.89	0.83	1.07	2.61	4.34	3.77	1.65
K <sub>2</sub> O	1.07	5.61	5.32	2.56	0.81	1.45	3.30
P <sub>2</sub> O <sub>5</sub>	0.04	0.13	0.12	0.17	0.15	0.19	0.15
LOI	0.60	2.8	1.70	1.80	3.00	2.4	3.3
Cr	14	18	20	26	18	18	113
Ni	3	7	6	7	3	11	35
Co	2.0	5.6	1.4		4.9	4.0	13.2
Sc	5.1	16.4	4.8		10.4	17.2	17.7
V	17	43	19	26	37	33	147
Cu	5		3	11	3		
Pb	18	22	27	5	19	19	22
Zn	34	69	63	31	99	110	87
Rb	61	176	148	102	37	30	104
Ba	152	520	627	400	103	1959	570
Sr	83	25	26	41	94	228	80
Ga	14.0	18.0	14.0	13.0	10.0	23.5	23.4
Ta	1.71	1.12	1.01		0.95	3.30	1.51
Nb	20.0	13.0	10.0	9.0	13.0	42.8	16.2
Hf	8.33	6.64	4.61		6.69	13.48	5.61
Zr	303	239	139	117	239	434	180
Y	47.0	41.0	41.0	31.0	55.0	72.7	19.9
Th	22.42	13.93	15.69		13.00	20.88	16.29
U	6.23	3.90	3.90		3.20	2.16	3.15
La	45.77	38.46	31.67		46.69	77.54	7.93
Ce	89.74	78.75	66.73		79.19	163.62	19.17
Nd	33.77	33.51	30.19		44.18	82.05	5.31
Sm	7.12	7.63	7.03		9.15	15.73	0.25
Eu	0.86	1.49	0.78		1.38	3.07	0.48
Tb	1.20	1.35	1.20		1.48	2.57	0.56
Yb	4.12	3.77	3.62		4.08	6.27	2.87
Lu	0.78	0.60	0.50		0.62	0.90	0.39

**INDEX TO 1998-1999 PUBLICATIONS  
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**National Topographic System in New Brunswick  
showing the Bathurst Mining Camp**

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## 21 I/07, Bouctouche

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DEHLER, S.A. 1998. Magnetic vertical derivative map, west central Nova Scotia, southeastern New Brunswick and western Prince Edward Island, with geology overlay. Geological Survey of Canada, Open File 3661, 1 coloured map [Scale: 1:3 000 000]

LYNCH, G., GILES, P.S., DEBLONDE, C., BARR, S.M., PIPER, S.W.J., ST. PETER, C., HÉTU, R.J., JOHNSON, S.C., PE-PIPER, G., ST-JEAN, R., MURPHY, J.B., CHANDLER, F.W., and BOEHNER, R.C. 1998. Magdalen Basin NATMAP –Onshore Geological Database. Geological Survey of Canada, Open File D3564, 1 CD-ROM

## 21 I/10, Richibucto

DEHLER, S.A. 1998. Magnetic anomaly map, west central Nova Scotia, southeastern New Brunswick and western Prince Edward Island, with geology overlay. Geological Survey of Canada, Open File 3660, 1 coloured map [Scale: 1:3 000 000]

DEHLER, S.A. 1998. Magnetic vertical derivative map, west central Nova Scotia, southeastern New Brunswick and western Prince Edward Island, with geology overlay. Geological Survey of Canada, Open File 3661, 1 coloured map [Scale: 1:3 000 000]

LYNCH, G., GILES, P.S., DEBLONDE, C., BARR, S.M., PIPER, S.W.J., ST. PETER, C., HÉTU, R.J., JOHNSON, S.C., PE-PIPER, G., ST-JEAN, R., MURPHY, J.B., CHANDLER, F.W., and BOEHNER, R.C. 1998. Magdalen Basin NATMAP –Onshore Geological Database. Geological Survey of Canada, Open File D3564, 1 CD-ROM

## 21 I/15, Pointe-Sapin

DEHLER, S.A. 1998. Magnetic anomaly map, west central Nova Scotia, southeastern New Brunswick and western Prince Edward Island, with geology overlay. Geological Survey of Canada, Open File 3660, 1 coloured map [Scale: 1:3 000 000]

DEHLER, S.A. 1998. Magnetic vertical derivative map, west-central Nova Scotia, southeastern New Brunswick and western Prince Edward Island, with geology overlay. Geological Survey of Canada, Open File 3661, 1 coloured map [Scale: 1:3 000 000]

LYNCH, G., GILES, P.S., DEBLONDE, C., BARR, S.M., PIPER, S.W.J., ST. PETER, C., HÉTU, R.J., JOHNSON, S.C., PE-PIPER, G., ST-JEAN, R., MURPHY, J.B., CHANDLER, F.W., and BOEHNER, R.C. 1998. Magdalen Basin NATMAP –Onshore Geological Database. Geological Survey of Canada, Open File D3564, 1 CD-ROM

## **21 J/03, Millville**

CONNELL, M.D. and HATTIE, D.W. 1998. Descriptions of samples analyzed for project "Lithogeochemical study of red manganiferous slate and black slate–chert in the Miramichi Terrane, New Brunswick", south of latitude 47°00'. Geological Survey of Canada, Open File 3584b, 158 p.

SEAMAN, A.A. 1998. Till geochemistry of the west half of the Millville (NTS 21 J/3) map area, York and Carleton counties, New Brunswick. *In* Current Research 1997. Edited by B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 98-4, pp. 75–92.

SEAMAN, A.A. 1999. Till geochemistry of the Millville (NTS 21 J/3) map area, York and Carleton counties, New Brunswick: site and geochemical data. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 99-11, 83 p. with field/location and analytical data files.

## **21 J/04, Woodstock**

CONNELL, M.D. and HATTIE, D.W. 1998. Descriptions of samples analyzed for project "Lithogeochemical study of red manganiferous slate and black slate–chert in the Miramichi Terrane, New Brunswick", south of latitude 47°00'. Geological Survey of Canada, Open File 3584b, 158 p.

## **21 J/06, Coldstream**

CONNELL, M.D. and HATTIE, D.W. 1998. Descriptions of samples analyzed for project "Lithogeochemical study of red manganiferous slate and black slate–chert in the Miramichi Terrane, New Brunswick", south of latitude 47°00'. Geological Survey of Canada, Open File 3584b, 158 p.

## **21 J/07, Napadogan**

CONNELL, M.D. and HATTIE, D.W. 1998. Descriptions of samples analyzed for project "Lithogeochemical study of red manganiferous slate and black slate–chert in the Miramichi Terrane, New Brunswick", south of latitude 47°00'. Geological Survey of Canada, Open File 3584b, 158 p.

## **21 J/10, Hayesville**

CONNELL, M.D. and HATTIE, D.W. 1998. Descriptions of samples analyzed for project "Lithogeochemical study of red manganiferous slate and black slate–chert in the Miramichi Terrane, New Brunswick", south of latitude 47°00'. Geological Survey of Canada, Open File 3584b, 158 p.

## **21 J/11, Juniper**

CONNELL, M.D. and HATTIE, D.W. 1998. Descriptions of samples analyzed for project "Lithogeochemical study of red manganiferous slate and black slate–chert in the Miramichi Terrane, New Brunswick", south of latitude 47°00'. Geological Survey of Canada, Open File 3584b, 158 p.

## **21J/15, Tuadook Lake**

CONNELL, M.D. and HATTIE, D.W. 1998. Descriptions of samples analyzed for project "Lithogeochemical study of red manganiferous slate and black slate-chert in the Miramichi Terrane, New Brunswick", south of latitude 47°00'. Geological Survey of Canada, Open File 3584b, 158 p.

## **21 J/16, McKendrick Lake**

CONNELL, M.D. and HATTIE, D.W. 1998. Descriptions of samples analyzed for project "Lithogeochemical study of red manganiferous slate and black slate-chert in the Miramichi Terrane, New Brunswick", south of latitude 47°00'. Geological Survey of Canada, Open File 3584b, 158 p.

## **21 O/01, Big Bald Mountain**

CONNELL, M.D. and HATTIE, D.W. 1998. Descriptions of samples analyzed for project "Lithogeochemical study of red manganiferous slate and black slate-chert in the Miramichi Terrane, New Brunswick", north of latitude 47°00'. Geological Survey of Canada, Open File 3584a, 244 p.

## **21 O/02, Serpentine Lake**

CONNELL, M.D. and HATTIE, D.W. 1998. Descriptions of samples analyzed for project "Lithogeochemical study of red manganiferous slate and black slate-chert in the Miramichi Terrane, New Brunswick", north of latitude 47°00'. Geological Survey of Canada, Open File 3584a, 244 p.

## **21 O/07, Nepisiguit Lakes**

CONNELL, M.D. and HATTIE, D.W. 1998. Descriptions of samples analyzed for project "Lithogeochemical study of red manganiferous slate and black slate-chert in the Miramichi Terrane, New Brunswick", north of latitude 47°00'. Geological Survey of Canada, Open File 3584a, 244 p.

## **21 O/08, California Lakes**

CONNELL, M.D. and HATTIE, D.W. 1998. Descriptions of samples analyzed for project "Lithogeochemical study of red manganiferous slate and black slate-chert in the Miramichi Terrane, New Brunswick", north of latitude 47°00'. Geological Survey of Canada, Open File 3584a, 244 p.

### **21 O/08a, b**

WILSON, R.A. 1998. Geology of the Roger Brook area (parts of NTS 21 O/08a, b, g, h), Bathurst Mining Camp, New Brunswick. *In* Current Research 1997. Edited by B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 98-4, pp. 93-121.

### **21 O/08g, h**

WILSON, R.A. 1998. Geology of the Roger Brook are (parts of NTS 21 O/08a, b, g, h), Bathurst Mining Camp, New Brunswick. *In* Current Research 1997. Edited by B.M.W. Carroll. New Brunswick Department of Natural

## 21 O/09, Tetagouche Lakes

CONNELL, M.D. and HATTIE, D.W. 1998. Descriptions of samples analyzed for project "Lithogeochemical study of red manganiferous slate and black slate-chert in the Miramichi Terrane, New Brunswick", north of latitude 47°00'. Geological Survey of Canada, Open File 3584a, 244 p.

## 21 O/10, Upsalquitch Forks

GIGGIE, K.V. 1999. Ground follow-up to the multi-sensor airborne geophysical survey in Central Restigouche County, New Brunswick: results and interpretation. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 99-9, 41 p.

GIGGIE, K.V. 1999. Geology of the Upsalquitch Forks area (NTS 21 O/10), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-1 [Scale: 1:50 000]

PARKHILL, M.A., PRONK, A.G., and FRISKE, P.W.B. 1998. A multimedia geochemical survey in the vicinity of copper skarn occurrences in the McKenzie Gulch area (parts of NTS 21 O/10, 11, and 15), northern New Brunswick. *In* Current Research 1997. Edited by B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 98-4, pp. 25-73.

PRONK, A.G., and FRISKE, P.W.B. 1998. Au, As, and Sb content of stream-sediment samples for part of the Upsalquitch Forks map area (NTS 21 O/10), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 98-46 [Scale: 1:50 000] / Teneur en Au, As, et Sb des échantillons de sédiments fluviaux d'une partie du secteur cartographique d'Upsalquitch Forks (SNRC 21 O/10), comté de Restigouche, Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 98-46 [échelle : 1:50 000]

PRONK, A.G., and FRISKE, P.W.B. 1999. Cu, Ni, and Co content of stream-sediment samples for part of the Upsalquitch Forks map area (NTS 21 O/10), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-12A [Scale: 1:50 000] / Teneur en Cu, Ni, et Co des échantillons de sédiments fluviaux d'une partie du secteur cartographique d'Upsalquitch Forks (SNRC 21 O/10), comté de Restigouche, Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 99-12A [échelle : 1:50 000]

PRONK, A.G., and FRISKE, P.W.B. 1999. Ni, Cr, and V content of stream-sediment samples for part of the Upsalquitch Forks map area (NTS 21 O/10), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-12B [Scale: 1:50 000] / Teneur en Ni, Cr, et V des échantillons de sédiments fluviaux d'une partie du secteur cartographique d'Upsalquitch Forks (SNRC 21 O/10), comté de Restigouche, Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 99-12B [échelle : 1:50 000]

PRONK, A.G., FRISKE, P.W.B., MCCURDY, M.W., and DAY, S.J. 1998. National Geochemical Reconnaissance: Regional stream-sediment and water geochemical data, northwestern New Brunswick. Geological Survey of Canada, Open File 3617. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 98-15. / Reconnaissance géochimique nationale; données géochimiques régionales sur les eaux et les sédiments fluviaux, nord-ouest du Nouveau-Brunswick. Commission géologique du Canada, dossier public 3617. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, dossier public 98-15.

- PRONK, A.G. and FRISKE, P.W.B. 1998. Multimedia geochemical data for the McKenzie Gulch area (parts of NTS 21 O/10, 11, and 15), northwestern New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 98-19. / Données géochimiques multimédias visant le secteur du ravin McKenzie (partie de 21 O/10, 11 et 15 du SNRC), dans le Nord-Ouest du Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, dossier public 98-19.
- PRONK, A.G. and FRISKE, P.W.B. 1998. A multimedia geochemical survey in the vicinity of copper skarn occurrences in the McKenzie Gulch area (parts of NTS 21 O/10, 11, and 15), northwestern New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 98-20. / Relevé géochimique multimédia à proximité des venues de skarns cuprifères du secteur du ravin McKenzie (partie de 21 O/10, 11 et 15 du SNRC), dans le Nord-Ouest du Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, dossier public 98-20.

## 21 O/11, Kedgwick

- GIGGIE, K.V. 1999. Ground follow-up to the multi-sensor airborne geophysical survey in Central Restigouche County, New Brunswick: results and interpretation. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 99-9, 41 p.
- GIGGIE, K.V. 1999. Geology of the Kedgwick area (NTS 21 O/11), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-2 [Scale: 1:50 000]
- GIGGIE, K.V. 1999. Figure 8. Airborne interpretation of the Upsalquitch Forks–Popelogan–Charlo River area. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-24 [Scale: 1:50 000]
- PARKHILL, M.A., PRONK, A.G., and FRISKE, P.W.B. 1998. A multimedia geochemical survey in the vicinity of copper skarn occurrences in the McKenzie Gulch area (parts of NTS 21 O/10, 11, and 15), northern New Brunswick. *In* Current Research 1997. Edited by B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 98-4, pp. 25–73.
- PRONK, A.G., and FRISKE, P.W.B. 1998. Au, As, and Sb content of stream-sediment samples for the Kedgwick map area (NTS 21 O/11), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 98-47 [Scale: 1:50 000] / Teneur en Au, As, et Sb des échantillons de sédiments fluviaux du secteur cartographique de Kedgwick (SNRC 21 O/11), comté de Restigouche, Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 98-47 [échelle : 1:50 000]
- PRONK, A.G., and FRISKE, P.W.B. 1999. Cu, Ni, and Co content of stream-sediment samples for the Kedgwick map area (NTS 21 O/11), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-13A [Scale: 1:50 000] / Teneur en Cu, Ni, et Co des échantillons de sédiments fluviaux du secteur cartographique de Kedgwick (SNRC 21 O/11), comté de Restigouche, Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 99-13A [échelle : 1:50 000]
- PRONK, A.G., and FRISKE, P.W.B. 1999. Ni, Cr, and V content of stream-sediment samples for the Kedgwick map area (NTS 21 O/11), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-13B [Scale: 1:50 000] / Teneur en Ni, Cr, et V des échantillons de sédiments fluviaux du secteur cartographique de Kedgwick (SNRC 21 O/11), comté de Restigouche, Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 99-13B [échelle : 1:50 000]

PRONK, A.G., FRISKE, P.W.B., MCCURDY, M.W., and DAY, S.J. 1998. National Geochemical Reconnaissance: Regional stream-sediment and water geochemical data, northwestern New Brunswick. Geological Survey of Canada, Open File 3617. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 98-15. / Reconnaissance géochimique nationale; données géochimiques régionales sur les eaux et les sédiments fluviaux, nord-ouest du Nouveau-Brunswick. Commission géologique du Canada, dossier public 3617. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, dossier public 98-15.

## 21 O/14, Menneval

PRONK, A.G., and FRISKE, P.W.B. 1998. Au, As, and Sb content of stream-sediment samples for part of the Menneval map area (NTS 21 O/14), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 98-48 [Scale: 1:50 000] / Teneur en Au, As, et Sb des échantillons de sédiments fluviaux d'une partie du secteur cartographique de Menneval (SNRC 21 O/14), comté de Restigouche, Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 98-48 [échelle : 1:50 000]

PRONK, A.G., FRISKE, P.W.B., MCCURDY, M.W., and DAY, S.J. 1998. National Geochemical Reconnaissance: Regional stream-sediment and water geochemical data, northwestern New Brunswick. Geological Survey of Canada, Open File 3617. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 98-15. / Reconnaissance géochimique nationale; données géochimiques régionales sur les eaux et les sédiments fluviaux, nord-ouest du Nouveau-Brunswick. Commission géologique du Canada, dossier public 3617. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, dossier public 98-15.

PRONK, A.G., and FRISKE, P.W.B. 1999. Cu, Ni, and Co content of stream-sediment samples for part of the Menneval map area (NTS 21 O/14), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-14A [Scale: 1:50 000] / Teneur en Cu, Ni, et Co des échantillons de sédiments fluviaux d'une partie du secteur cartographique d'Upsalquitch Forks (SNRC 21 O/14), comté de Restigouche, Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 99-14A [échelle : 1:50 000]

PRONK, A.G., and FRISKE, P.W.B. 1999. Ni, Cr, and V content of stream-sediment samples for part of the Menneval map area (NTS 21 O/14), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-14B [Scale: 1:50 000] / Teneur en Ni, Cr, et V des échantillons de sédiments fluviaux d'une partie du secteur cartographique de Menneval (SNRC 21 O/14), comté de Restigouche, Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 99-14B [échelle : 1:50 000]

## 21 O/15, Atholville

GIGGIE, K.V. 1999. Ground follow-up to the multi-sensor airborne geophysical survey in Central Restigouche County, New Brunswick: results and interpretation. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 99-9, 41 p.

GIGGIE, K.V. 1999. Geology of the Atholville area (NTS 21 O/15), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-3 [Scale: 1:50 000]

GIGGIE, K.V. 1999. Figure 8. Airborne interpretation of the Upsalquitch Forks–Popelogan–Charlo River area. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-24 [Scale: 1:50 000]

- PARKHILL, M.A., PRONK, A.G., and FRISKE, P.W.B. 1998. A multimedia geochemical survey in the vicinity of copper skarn occurrences in the McKenzie Gulch area (parts of NTS 21 O/10, 11, and 15), northern New Brunswick. *In* Current Research 1997. Edited by B.M.W. Carroll. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Mineral Resource Report 98-4, pp. 25-73.
- PRONK, A.G., and FRISKE, P.W.B. 1998. Au, As, and Sb content of stream-sediment samples for parts of the Atholville map area (NTS 21 O/15), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 98-49 [Scale: 1:50 000] / Teneur en Au, As, et Sb des échantillons de sédiments fluviaux d'une partie du secteur cartographique d'Atholville (SNRC 21 O/15), comté de Restigouche, Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 98-49 [échelle : 1:50 000]
- PRONK, A.G., and FRISKE, P.W.B. 1999. Cu, Ni, and Co content of stream-sediment samples for part of the Atholville map area (NTS 21 O/15), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-15A [Scale: 1:50 000] / Teneur en Cu, Ni, et Co des échantillons de sédiments fluviaux d'une partie du secteur cartographique d'Atholville (SNRC 21 O/15), comté de Restigouche, Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 99-15A [échelle : 1:50 000]
- PRONK, A.G., and FRISKE, P.W.B. 1999. Ni, Cr, and V content of stream-sediment samples for part of the Atholville map area (NTS 21 O/15), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-15B [Scale: 1:50 000] / Teneur en Ni, Cr, et V des échantillons de sédiments fluviaux d'une partie du secteur cartographique d'Atholville (SNRC 21 O/15), comté de Restigouche, Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 99-15B [échelle : 1:50 000]
- PRONK, A.G., FRISKE, P.W.B., MCCURDY, M.W., and DAY, S.J. 1998. National Geochemical Reconnaissance: Regional stream-sediment and water geochemical data, northwestern New Brunswick. Geological Survey of Canada, Open File 3617. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 98-15. / Reconnaissance géochimique nationale; données géochimiques régionales sur les eaux et les sédiments fluviaux, nord-ouest du Nouveau-Brunswick. Commission géologique du Canada, dossier public 3617. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, dossier public 98-15.

## 21 O/16, Charlo

- GIGGIE, K.V. 1999. Ground follow-up to the multi-sensor airborne geophysical survey in Central Restigouche County, New Brunswick: results and interpretation. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 99-9, 41 p.
- GIGGIE, K.V. 1999. Geology of the west half of the Charlo area (NTS 21 O/16), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-4 [Scale: 1:50 000]
- GIGGIE, K.V. 1999. Figure 8. Airborne interpretation of the Upsalquitch Forks-Popelogan-Charlo River area. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-24 [Scale: 1:50 000]
- PRONK, A.G., and FRISKE, P.W.B. 1998. Au, As, and Sb content of stream-sediment samples for parts of the Charlo map area (NTS 21 O/16), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 98-50 [Scale: 1:50 000] / Teneur en Au, As, et Sb des échantillons de sédiments fluviaux d'une partie du secteur cartographique de Charlo (SNRC 21 O/16), comté de Restigouche, Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 98-50 [échelle : 1:50 000]

- PRONK, A.G., and FRISKE, P.W.B. 1999. Cu, Ni, and Co content of stream-sediment samples for part of the Charlo map area (NTS 21 O/16), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-16A [Scale: 1:50 000] / Teneur en Cu, Ni, et Co des échantillons de sédiments fluviaux d'une partie du secteur cartographique de Charlo (SNRC 21 O/16), comté de Restigouche, Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 99-16A [échelle : 1:50 000]
- PRONK, A.G., and FRISKE, P.W.B. 1999. Ni, Cr, and V content of stream-sediment samples for part of the Charlo map area (NTS 21 O/16), Restigouche County, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-16B [Scale: 1:50 000] / Teneur en Ni, Cr, et V des échantillons de sédiments fluviaux d'une partie du secteur cartographique de Charlo (SNRC 21 O/16), comté de Restigouche, Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 99-16B [échelle : 1:50 000]
- PRONK, A.G., FRISKE, P.W.B., MCCURDY, M.W., and DAY, S.J. 1998. National Geochemical Reconnaissance: Regional stream-sediment and water geochemical data, northwestern New Brunswick. Geological Survey of Canada, Open File 3617. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 98-15. / Reconnaissance géochimique nationale; données géochimiques régionales sur les eaux et les sédiments fluviaux, nord-ouest du Nouveau-Brunswick. Commission géologique du Canada, dossier public 3617. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, dossier public 98-15.

## 21 P/04, Sevogle

- CONNELL, M.D. and HATTIE, D.W. 1998. Descriptions of samples analyzed for project "Lithogeochemical study of red manganiferous slate and black slate-chert in the Miramichi Terrane, New Brunswick", north of latitude 47°00'. Geological Survey of Canada, Open File 3584a, 244 p.
- DOIRON, A. et BOISVERT, É. 1999. La géochimie des tills de la région de Sevogle (SNRC 21 P/4W), comtés de Northumberland et Gloucester, Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des Ressources minières et de l'énergie, dossier public 99-3, 133 p. / Till geochemistry of the Sevogle area (NTS 21 P/4W), Northumberland and Gloucester counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Open File 99-3, 133 p.
- DOIRON, A. et BOISVERT, É. 1999. Cu, Pb, Zn, Au, Ag, As, W, Sb et Mo géochimie du till (fraction <0,63 mm), Sevogle (SNRC 21 P/4, moitié ouest), Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des Ressources minières et de l'énergie, planche 99-6. / Cu, Pb, Zn, Au, Ag, As, W, Sb, and Mo till geochemistry (<0.63 mm fraction), Sevogle (NTS 21 P/4, west half), New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-6.
- DOIRON, A. et BOISVERT, É. 1999. Br, Ca, Ce, Cs, Eu, Ga, Hf, Ho, La, Lu, Na, et Nd géochimie du till (fraction <0,63 mm), Sevogle (SNRC 21 P/4, moitié ouest), Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des Ressources minières et de l'énergie, planche 99-7. / Br, Ca, Ce, Cs, Eu, Ga, Hf, Ho, La, Lu, Na, and Nd till geochemistry (<0.63 mm fraction), Sevogle (NTS 21 P/4, west half), New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-7.
- DOIRON, A. et BOISVERT, É. 1999. Co, Ni, Cr, U, Ba, Nb, Rb, Sr et Fe géochimie du till (fraction <0,63 mm), Sevogle (SNRC 21 P/4, moitié ouest), Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des Ressources minières et de l'énergie, planche 99-8. / Co, Ni, Cr, U, Ba, Nb, Rb, Sr and Fe till geochemistry (<0.63 mm fraction), Sevogle (NTS 21 P/4, west half), New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-8.

DOIRON, A. et BOISVERT, É. 1999. Sc, Sm, Ta, Tb, Th, V, Y, Yb, et Zr géochimie du till (fraction <0,63 mm), Sevogle (SNRC 21 P/4, moitié ouest), Nouveau-Brunswick. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des Ressources minières et de l'énergie, planche 99-9. / Sc, Sm, Ta, Tb, Th, V, Y, Yb, and Zr till geochemistry (<0.63 mm fraction), Sevogle (NTS 21 P/4, west half), New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-9.

## **21 P/05, Nepisiguit Falls**

CONNELL, M.D. and HATTIE, D.W. 1998. Descriptions of samples analyzed for project "Lithogeochemical study of red manganiferous slate and black slate-chert in the Miramichi Terrane, New Brunswick", north of latitude 47°00'. Geological Survey of Canada, Open File 3584a, 244 p.

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PARKHILL, M.A. and DICKSON, M.L. 1999. Location of basal till samples and ice-flow indicators in the Nepisiguit Falls map area (NTS 21 P/05), Gloucester and Northumberland counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-27A

PARKHILL, M.A. 1999. Geological compilation of the Nepisiguit Falls map area (NTS 21 P/05), Gloucester and Northumberland counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-27B

## **21 P/12, Bathurst**

CONNELL, M.D. and HATTIE, D.W. 1998. Descriptions of samples analyzed for project "Lithogeochemical study of red manganiferous slate and black slate-chert in the Miramichi Terrane, New Brunswick", north of latitude 47°00'. Geological Survey of Canada, Open File 3584a, 244 p.

## **21 P/13, Pointe Verte**

CONNELL, M.D. and HATTIE, D.W. 1998. Descriptions of samples analyzed for project "Lithogeochemical study of red manganiferous slate and black slate-chert in the Miramichi Terrane, New Brunswick", north of latitude 47°00'. Geological Survey of Canada, Open File 3584a, 244 p.

## **21 P/15, Caraquet**

BÉRUBÉ, D. 1999. Étude photogrammétrique du déplacement de la ligne de côte de la flèche de Maisonnnette, baie de Caraquet, Nouveau-Brunswick : 1944–1991. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 99-28A [échelle : 1:10 000]

BÉRUBÉ, D. 1999. Étude photogrammétrique du déplacement de la ligne de rivage de la flèche de Maisonnnette, baie de Caraquet, Nouveau-Brunswick : 1944–1991. Ministère des Ressources naturelles et de l'Énergie du Nouveau-Brunswick, Division des ressources minières et de l'énergie, planche 99-28B [échelle : 1:10 000]



## Conversion Factors: Imperial and International System of Units (SI)

The following multipliers should be used to convert imperial units to SI units or SI units to imperial units:

### CONVERSION FROM SI TO IMPERIAL

### CONVERSION FROM IMPERIAL TO SI

<i>SI Unit</i>	<i>Multiply by</i>	<i>Gives</i>	<i>Imperial Unit</i>	<i>Multiply by</i>	<i>Gives</i>
<b>LENGTH</b>					
1 mm	0.039 37	inches	1 inch	<b>25.4</b>	mm
1 cm	0.393 70	inches	1 inch	<b>2.54</b>	cm
1 m	3.280 84	feet	1 foot	<b>0.304 8</b>	m
1 m	0.049 709 7	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	<b>1.609 344</b>	km
<b>AREA</b>					
1 cm <sup>2</sup>	0.155 0	square inches	1 square inch	<b>6.451 6</b>	cm <sup>2</sup>
1 m <sup>2</sup>	10.763 9	square feet	1 square foot	<b>0.092 903 04</b>	m <sup>2</sup>
1 km <sup>2</sup>	0.386 10	square miles	1 square mile	2.589 988	km <sup>2</sup>
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
<b>VOLUME</b>					
1 cm <sup>3</sup>	0.061 02	cubic inches	1 cubic inch	<b>16.387 064</b>	cm <sup>3</sup>
1 m <sup>3</sup>	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m <sup>3</sup>
1 m <sup>3</sup>	1.308 0	cubic yards	1 cubic yard	0.764 555	m <sup>3</sup>
<b>CAPACITY</b>					
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	<b>4.546 090</b>	L
<b>MASS</b>					
1 g	0.035 273 96	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.32 150 75	ounces (troy)	1 ounce (troy)	<b>31.103 476 8</b>	g
1 kg	2.204 62	pounds (avdp)	1 pound (avdp)	<b>0.453 592 37</b>	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	<b>907.184 74</b>	kg
1 t	1.102 311	tons (short)	1 ton (short)	<b>0.907 184 74</b>	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	<b>1016.046 908 8</b>	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	<b>1.016 046 908 8</b>	t
<b>CONCENTRATION</b>					
1 g/t	0.029 166 6	ounce (troy)/ton (short)	1 ounce (troy)/ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ton (short)	1 pennyweight/ton (short)	1.714 285 7	g/t

### OTHER USEFUL CONVERSION FACTORS

1 ounce (troy)/ton (short)	20.0	pennyweights/ton (short)
1 pennyweight/ton (short)	0.05	ounce (troy)/ton (short)

NOTE: Conversion factors in bold type are exact.

SOURCE: Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by The Mining Association of Canada in cooperation with the Coal Association of Canada.